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RESEARCH ON ABSOLUTE GRAVITY VARIATIONS IN GEODYNAMIC LABORATORY IN KSIĄŻ IN THE PERIOD OF 2007- 2011

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ABSTRACT. In 2006 a gravimetric pavilion was installed inside the Geodynamic Laboratory (LG) in Książ. The pavilion was equipped with two pillars intended to serve relative and absolute gravimetric measurements. Installation of measurement platform for absolute gravity measurements inside gravimetric pavilion of LG made it possible to perform four sessions of absolute gravity measurements: two of them in 2007 (June 10-12 and Nov. 21-22), one in 2008 (Apr. 21-22) and one in 2011 (June 19-21). In 2007 the absolute measurements were performed using two FG5 ballistic gravimeters. In April 2007 the measurements were performed by Dr Makinen from Geodetic Institute of Finnish Academy of Science with application of FG5 No. 221 absolute gravimeter. In June 2007 and in the years 2008 and 2011 such gravimetric measurements were performed by the team from Department of Geodesy and Astronomical Geodesy of Warsaw University of Technology using FG5 No. 230 absolute gravimeter. Elaboration of observation sessions from both gravimeters was performed in the Department of Higher Geodesy following the procedures used in constituting of uniform gravimetric system of geodynamic polygons reference. This constituting of gravimetric system comprised inter alia application of identical models of lithospheric tides (global model by Wenzel, 1997) and ocean tides (Schwiderski, 1980) (reduction of absolute measurements with tidal signals).

Observations performed during summer of 2007, autumn of 2007, and spring of 2008 and 2011 indicated existence of small changes of absolute gravity of the order of 1 μGal. Maxima of accelerations appear in the spring period, and minima in the autumn period. This effect is connected with the influence of global hydrological factors the annual amplitude of which is ca 1,5 μGal and achieve extreme values in the spring-autumn interval.

Very small value of observed amplitude of gravity changes in the period of extreme variability suggests that the observed gravity changes in LG are caused only by global phenomenon. This proves high degree of „independence" of gravimetric measurement base in LG from the local environmental factors such as ground water level variations, ground humidity, impact of snow cover, etc. At this moment the instrumental environment of absolute measurements obtains particular value, especially in the case of the tiltmeters and relative the gravimeter Lacoste&Romberg (LR-648). The relative gravity measurements as performed simultaneously with absolute gravity measurements enable us to determine the local tidal ephemeredes which makes it possible to replace the global tidal modal with ocean tidal model with the more realistic, locally determined tidal parameters (the local tidal ephemeredes).

Keywords: gravity measurements, gravimeters, direct and indirect tides, tidal modelling

INTRODUCTION

Geodynamic Laboratory (LG) of Space Research Center (SRC) is situated on $50^{0}51'$ N and $16^{0}18'$ E in the horizontal underground corridors build under the Książ castle during the World War II. Entrance to the underground is situated 340 meters above sea level and ca 52 meters under the Earth surface in strongly bound Carbonian conglomerates, which consist of metamorphic gneiss rocks originating in the nearby Sowie Mountains (Kaczorowski, Wojewoda, 2011). After 2000 there occurred a rapid development of the LG instrumentation, installation of connection systems, power supply, and construction of a gravimetric pavilion. In 2007 there was installed in the gravimetric pavilion the LCR-648 tidal relative gravimeter which had been moved from the gravimetric station in Warsaw. Gravimetric pavilion in the LG was equipped with two pillars for relative and absolute measurements. The pillar for relative measurements was situated in a thermostatic room separated from the rest of the pavilion. In 2008 to the gravimetric pillars a sequence of precise leveling was adjusted. In the gravimetric pavilion absolute gravity and vertical gradient of gravity were determined. Construction of the gravimetric pavilion in the underground made it possible to perform continuous relative gravimetric observations as well as to execute the absolute gravity measurements. It enabled us to calibrate the relative gravimeter, and thereafter to apply the local ephemeredes for reduction of absolute measurements. Natural environment surrounding the LG is favorable for gravimetric research. Książ Carbonian conglomerates are unsaturated and their mechanical strength is much greater than the strength of surrounding rocks. Mechanical resistance of these conglomerates assured preservation of integrity of the Książ massif in the geological time scale. In the massif surrounding the laboratory, water is present in the rock cracks and faults only and does not form any aquifers. Constant level of water is preserved in the lowest part of the LG underground corridors. The excess of water flows out of the underground through rocky steeps. Annual temperature variations in the underground amount to some tenths of a degree and diurnal variations amount to some hundredths of a degree. Small variations of temperature results in natural thermostatic condition of the measuring instruments and minimizes instrumental thermal effects.

GRAVIMETRIC PAVILION IN THE GEODYNAMIC LABORATORY

Construction of the gravimetric pavilion in the LG was started in 2005 in order to ensure favorable conditions for performing permanent gravimetric measurements and to hold gravimetric sessions of absolute measurements.

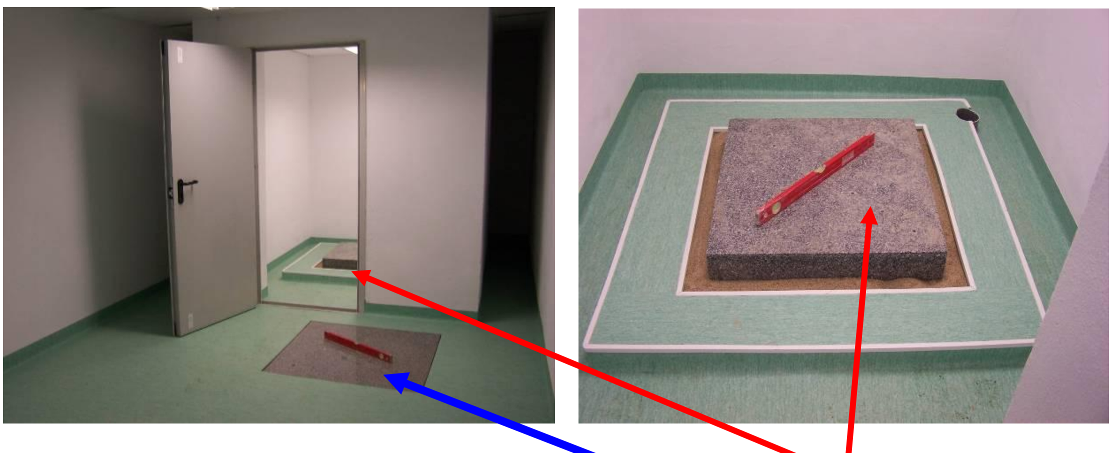

Fig.1. Interior of the pavilion with two pillars for absolute and relative gravity measurements

Direct situating the gravimetric site in the underground corridors of the laboratory was impossible because of high relative humidity (ca 90%) as well as low temperature (ca 10^{O}C). As a construction site of the gravimetric pavilion a part of the corridor with dimensions of 14x4.5 m and ca 5 m. high, neighboring with the pendulum clinometers room was chosen. Gravimetric pavilion was equipped with two separate pillars for relative and absolute measurements. Excavations reaching solid rock situated ca 1 m. under the floor level were executed under the measurement pillars. The pillar for the relative measurements was formed as a concrete box of ca 20 cm. thick walls and horizontal dimensions 110x110 cm. filled with quartz gravel and styrofoam plates. On the surface of the pillar a granite plate of ca 150 kg weight and 80x80x15 cm dimensions was placed. The pillar for the absolute measurements was constructed as a solid block of concrete bound with the rocky base and covered with a granite plate.

GRAVIMETRIC MEASUREMENTS IN THE LG

In the second half of 2007 in the gravimetric pavilion in the LG permanent measurements of gravity changes were started with application of the laboratory LCR-648 relative gravimeter equipped with the feedback system. The relative gravimeter is another instrument in laboratory – besides the horizontal pendula (Kaczorowski, 2008) and water-tubes tiltmeters (Kaczorowski, 2006) for registering tidal phenomena. Installation of the site for the absolute measurements in the gravimetric pavilion of the LG in Książ made it possible to perform four sessions of absolute measurements: two in 2007 (June, 10-12, and November, 21-22),and one in 2008 (April, 21-22) and next in 2011 (June, 19-22). The absolute measurements were performed using two FG5 ballistic gravimeters. In June 2007, April 2008, and June 2011 the team of Department of Higher Geodesy and Geodetic Astronomy of Warsaw University of Technology performed absolute measurements of gravity applying the FG5 No. 230 gravimeter. Dr. J. Makinen performed session in November 2007 using the FG5 No. 221 gravimeter from Geodetic Institute of Finnish Academy of Sciences. The Finnish team applied for their measurements the standard daily observation session.

Fig.2. FG5 gravimeter on the measurement site in the LG in Książ
during the 2007, June, 10 session

The Polish team prolonged their observation session a little so as to perform the calibration of the LCR 648 spring gravimeter installed in 2007 on the measurement site of the LG in Książ. The observation sessions were processed according the time schedule:

- June 2007 – session consisting of 31 observation series with hourly intervals comprising 100 drops in every series;
- November 2007 – session consisting of 43 observation series with half hour intervals comprising 50 drops in every series,
- April 2008 – session consisting of 37 observation series with hourly intervals comprising 100 drops in every series;
- June 2011 – session consisting of 60 observation series with hourly intervals comprising 100 drops in every series.

The elaboration of observations from the two absolute gravimeters was performed by the team of Department of Higher Geodesy and Geodetic Astronomy of Warsaw University of Technology according to the procedures applied in the frame of forming a uniform geodynamic polygons system (Walo et al., 2010 and Olszak et al., 2010). It also included application of identical global lithospheric tidal models (Wenzel, 1997) and oceanic tidal model (Schwiderski, 1980) and application of identical sources of parameters applied for determination of corrections of the observed gravity. Table 1 presents the summary of results of four gravimetric series of absolute measurements in chronological order. Presented gravity values were related to the level of center of gravimetric sign, i.e to the level of pillar (h=0). Table 1 summarizes the values of errors of singular gravity observation m_g for singular observation series.

Tab.1 Summary of final results of gravimetric sessions of absolute measurements performed in 2007-2011 in the LG in Książ

No	Time	gravity	m_g	Instrument
1	06.2007	981056796,4 μGal	1,99 μGal	FG-5 230
2	11.2007	981056791,2 μGal	2,80 μGal	FG-5 221
3	4.2008	981056793,3 μGal	2,06 μGal	FG-5 230
4	6.2011	981056793,6 μGal	1,97 μGal	FG-5 230

Observation series of the two absolute gravimeters were corrected basing on the results of the International Calibration Campaign ECAG2007 for which the calibration difference is equal to 0,1 μGal for the applied models (Francis et al., 2008). The observations performed in summer 2007, autumn 2007, and spring 2008 showed existence of minor changes of absolute gravity in the LG of about 2μGal. The largest gravity variations appear in the interval of Spring (maxima) - Autumn (minima).This effect is caused by the global hydrological factors, the amplitude of which is ca 1,5 μGal and achieves extreme values in the Spring-Autumn interval. Very small value of the gravity difference in the interval of largest variability suggests that in the LG only the global phenomena affect gravity. This confirms independence of the gravimetric site in the LG from local environmental disturbances such as groundwater level variations, ground humidity, impact of snow cover, etc. Determined values of gravity were compared with the values of gravitational signal produced by yearly changes of global groundwater resources as calculated applying WGHM (WaterGap Hydrology Model) model. Results of this comparison for the Książ LG are presented in Fig. 3 (WZIONTEK et al., 2009).

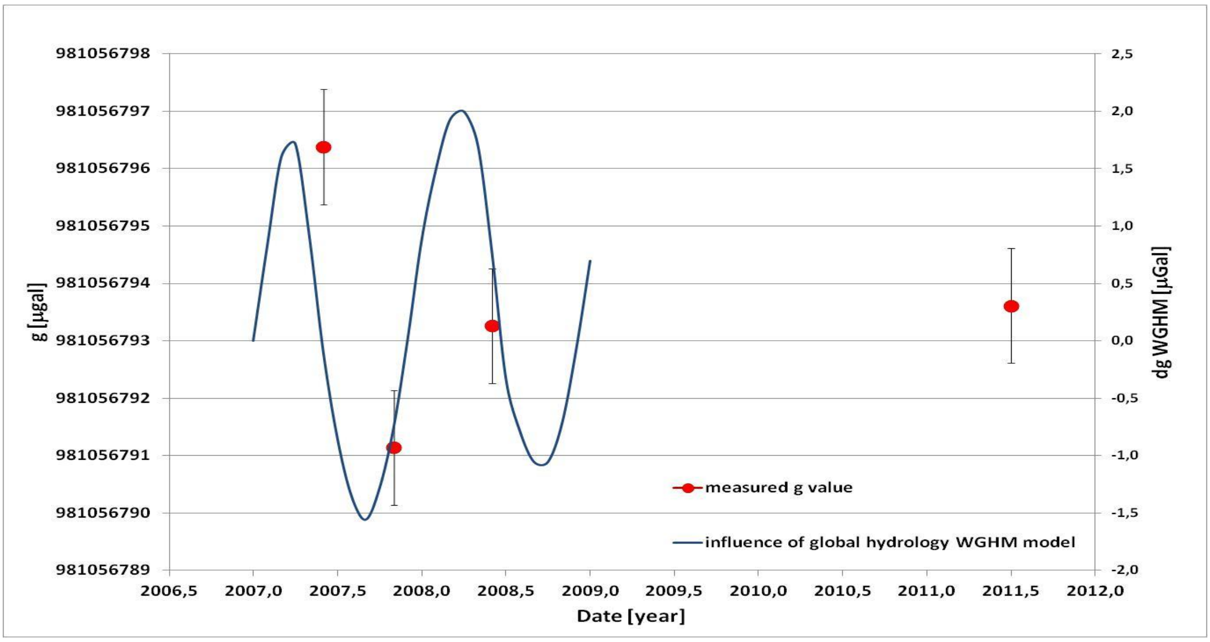

Fig.3. Seasonal changes in gravitational signal as determined basing on the WGHM global hydrological model and absolute values of gravity obtained on the gravimetric site in the LG during the four measurement sessions

Accuracy characteristics of determination of absolute gravity

During the absolute gravity measurements the operator can inspect several characteristics describing accuracy of singular drop, accuracy of singular observation series, as well as of the whole observation session consisting of teens of observation series. For the singular drop, characteristics of residuals obtained from equation of way of drop is presented. These are the differences between the measured values of way and time of drop and the model values determined basing on the equation of way determined with application of the minimum square method from gravity values. In case of exact adjustment the residual will be decreased to zero. Acceptable values of residuals which are of casual character do not exceed 5 nm. For the singular observation series as well as for the whole measurement session a direct statistical analysis is based on determination of standard deviation – the average value obtained basing on singular drops in the singular series or average value obtained from observations series for the whole observation session.

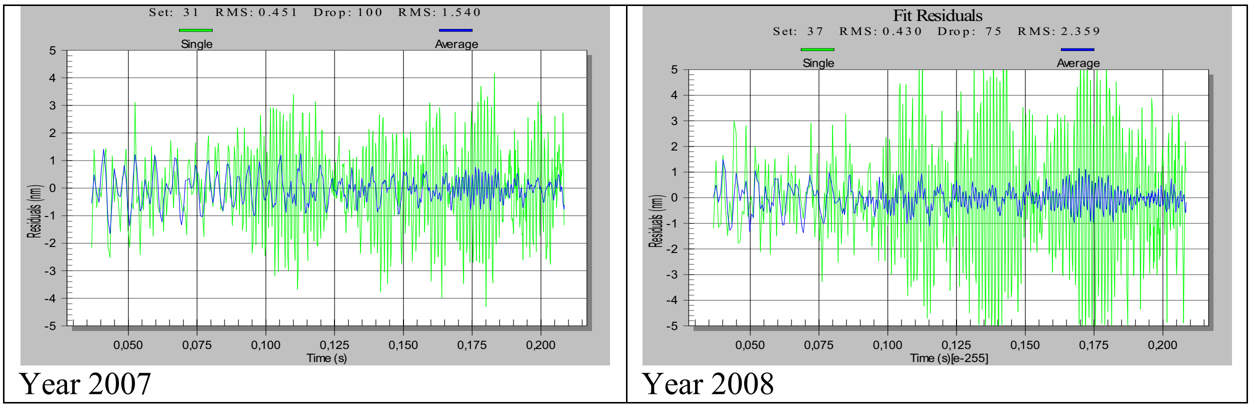

Fig.4. Plot of residuals of singular drops from two measurement series

Typical characteristics for absolute gravity measurement in Książ LG are presented in Fig. 4 and Fig.5. The presented characteristics concern the singular drop, the singular observation series and the summary of whole session. A typical gravity observation and a typical observation series were selected so that they would in a representative manner characterize the observation conditions on gravity measurement platform in LG (Fig.4 and Fig.5). In Fig.4 residuals for singular drop were marked in green and residuals for all the drops from the whole observation series were marked in blue. The obtained amplitudes of the residuals do not exceed ±5 nm for the singular drop. Average values of residuals are not of casual character. In the plots the short period oscillations of ±1 nm magnitude can be seen. The level of obtained errors (totally acceptable) is typical of gravimetric pillar in the LG as covered with solid, elastic granite plate which transmits oscillations caused by drops and lifting of the test mass in the vacuum tube of gravimeter. In Fig.5 values of gravity for single drop are presented.

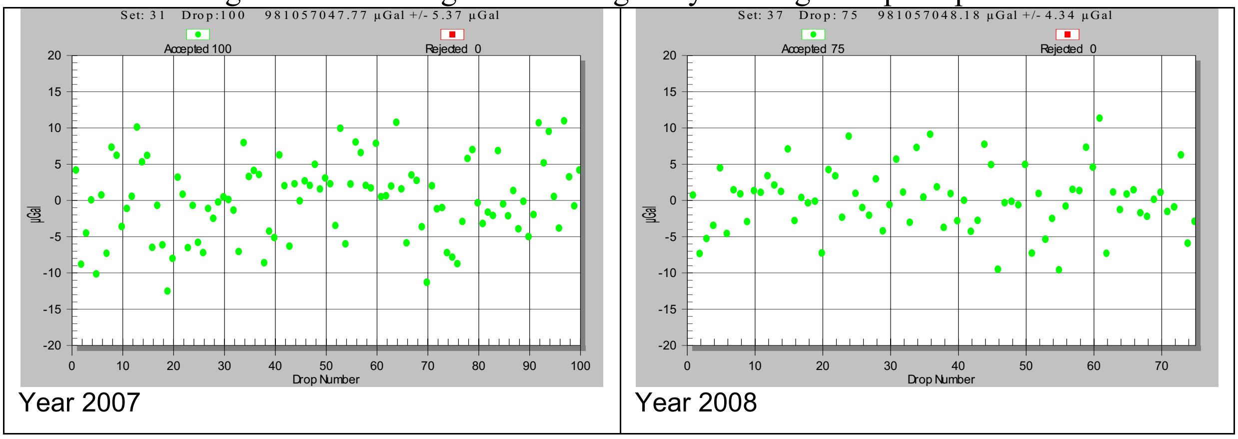

Fig.5. Distribution of gravity values for single observation in two observation series

The obtained results (Fig.5) show a low level of seismic signals in the LG as well as the random character of apparent errors in relation to the mean value which define most appropriate conditions for the absolute gravity measurements in LG. Essential in evaluation of the quality of the measure site in the LG are small errors of singular observation ±5-6 μGal. Fig.6 presents values of gravity as determined in hourly observation series with marked values of interval of errors describing the error of singular observation in each observation series.

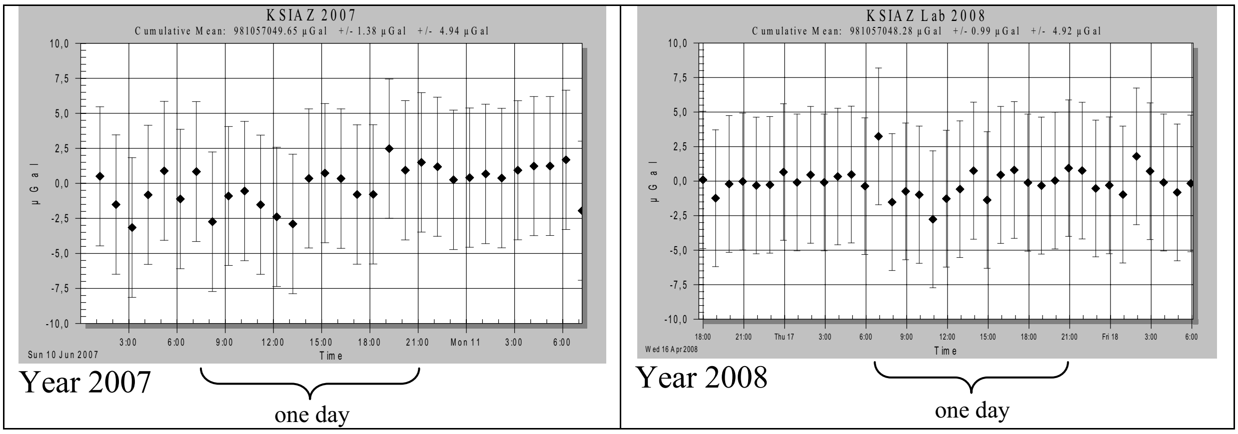

Fig.6 Plot of values of gravity together with interval of errors describing the error of single observation in hourly observation series

The plots in Fig. 6 present a high stability of hourly determined gravity values together with similar values of standard deviation in separate observation series. Influence of micro-seismic signals (oscillations) as most probably generated by daily activity of Wałbrzych agglomeration can be noticed in a small degree in measurements .

CONCLUSIONS

The results of analysis of four observation series indicate most appropriate natural conditions in the LG surroundings of Książ, encouraging performance of absolute gravity measurements. The gravimetric measurement site in the LG is featured with very low level of noises as produced by the local environmental factors, such ground water level variations, humidity of ground, impact of snow cover, etc. The absolute measurements executed in the LG are featured with small errors of singular observation which indicate very good seismic conditions for absolute measurements in the LG. At the same time the random character of apparent errors of observation is visible. In consideration of measurement and seismic conditions of measurement site in the Książ LG should be treated as a foremost location for ballistic gravimeter calibration in Poland. Detailed analysis of accuracy characteristics of absolute measurements as executed at gravimetric site in the LG in Książ qualifies the gravimetric site in the LG for one of exclusive research sites capable to interpret secular phenomena of absolute gravity variations.

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