# UNIFIED GRAVIMETRIC REFERENCE FRAME FOR POLISH IGS/EPN STATIONS AND GEODYNAMIC TEST FIELDS

**Janusz Walo, Tomasz Olszak, Andrzej Pachuta,**
**Dominik Próchniewicz, Ryszard Szpunar**

**Department of Geodesy and Geodetic Astronomy**
**Warsaw University of Technology**
**Plac Politechniki 1, 00-661 Warsaw**

## 1. INTRODUCTION

**Absolute gravity values are useful as a complement of position monitoring at IGS/EPN permanent stations to regional geodynamic purposes. Also absolute gravity stations in region of geodynamical test field are necessary as precise reference level and for relative gravimetric measurements to calibration purposes.**

**From 2007 to 2008 absolute gravimetric network to unify gravimetric reference level for GNSS permanent stations and geodynamic test fields have been established in Poland. Within a framework of this project, six absolute gravity stations were established near by IGS/EPN stations and seven points in two geodynamic test fields: Pieniny Test Field (3 points) and Sudeten Network (4 points).**

**Final results of establishment of Unified Gravimetric Reference Frame for Polish IGS/EPN Station and Geodynamic Test Fields are presented in the paper. Some issues with changing gravity reference level (comparing to Polish Fundamental Gravimetric Network), instruments parameters and results of g determinations are also discussed.**

## 2. PROJECT REALIZATION

**Realization of the project aimed at provision of a uniform gravimetric reference frame for Polish permanent GNSS stations and geodynamic traverses all over the country, realized with the highest currently available accuracy. Therefore, all Polish IGS permanent stations (Józefosław, Borowa Góra, Lamówko, Borowiec, Wrocław) as well as one EPN station (Krakow) were included into this project. In addition, seven absolute gravimetric points were established on the area of two important geodynamic test fields: Pieniny Test Field and Sudety Test Field. Figure 1 presents location of established gravimetric points.**

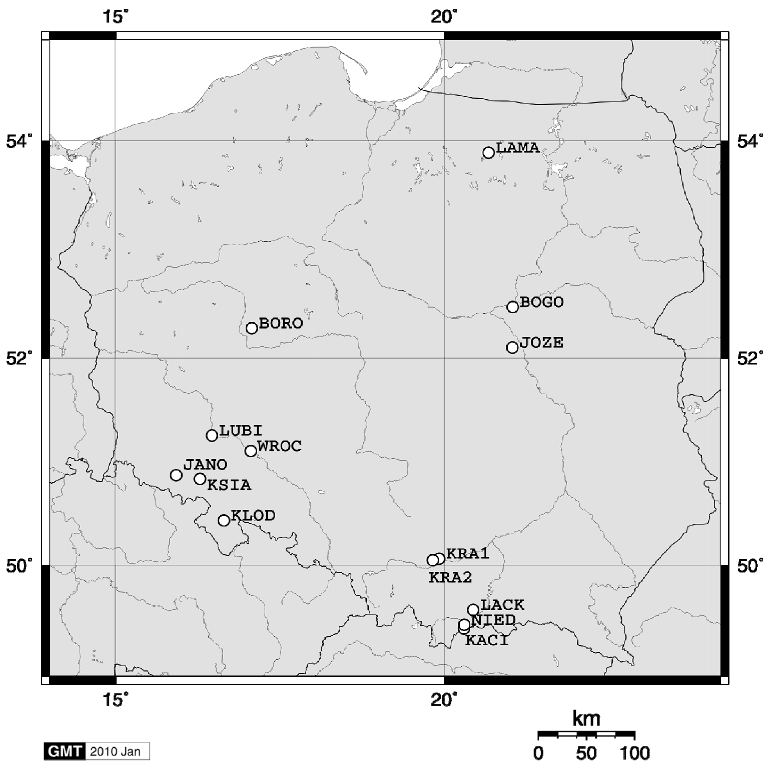


**Fig. 1. Gravimetric points consist of Unified Gravimetric Reference Frame.**

**The gravimetric points were located in buildings close to the GNSS points so that they are subject to the same tectonic and environmental effects. All points have a permanent stabilisation (concrete pole) which ensures good conditions for absolute measurements. In addition, all points have evaluated geodetic coordinates and are controlled with the basic gravimetric and levelling networks. Due to the fact that the points may be used as points for relative measurements, they have defined vertical gradients of gravitational acceleration. Two eccentric points were selected for each of these points outside of the building.**

**The absolute measurements were conducted using the FG-5 No. 230 absolute gravimeter in 24-hour observation sessions. The observations were performed in one hour intervals of time, 100 drops in each series (totally about 2400 drops). The final gravity value was calculated taking the following into consideration:**

**effects connected with Earth and Oceanic tides for elastic Earth model using ETGTAB software;**
**air pressure effects (with coefficient -0,3 µGal /mbar);**
**polar motion (IERS EOP products);**
**decrease of gravitational acceleration due to the actual vertical gradient of terrestrial gravity force.**

**This way of measurements made it possible to achieve accuracy of evaluation of gravitational acceleration value with a mean error on the level of 2-3 µGal. Results of gravitational acceleration values and their mean errors are presented in Table 1. Sign s denotes drop scatter (standard deviation of g values), $m_{dg/dh}$ is the error of vertical gradient, T.U. denotes Total Uncertainty which can be interpreted as a error of g values.**

**Tab. 1. Values of gravity for Unified Gravimetric Reference Frame**

| Name | Date | g value [μGal] | s [μGal] | $m_{dg/dh}$ [μGal/m] | T.U. [μGal] |
|---|---|---|---|---|---|
| BOGO | 2007 | 981 250 553,2 | 1,2 | 1,6 | 2,6 |
| | 2008 | 981 250 551,0 | 1,6 | 1,6 | 2,7 |
| BORO | 2007 | 981 246 136,0 | 1,8 | 3,4 | 4,6 |
| | 2008 | 981 246 133,7 | 1,2 | 3,4 | 4,6 |
| JOZE | 2007 | 981 214 010,6 | 1,6 | 1,9 | 3,0 |
| | 2008 | 981 214 008,6 | 2,0 | 1,9 | 3,0 |
| KRA1 | 2007 | 981 039 295,0 | 1,6 | 3,2 | 4,5 |
| | 2008 | 981 039 299,5 | 1,1 | 3,2 | 4,4 |
| KRA2 | 2007 | 981 021 432,8 | 2,2 | 1,9 | 3,0 |
| | 2008 | 981 021 432,9 | 1,5 | 1,9 | 2,9 |
| LAMA | 2007 | 981 377 608,0 | 1,6 | 2,0 | 3,1 |
| | 2008 | 981 377 609,2 | 2,2 | 2,0 | 3,1 |
| WROC | 2007 | 981 145 887,3 | 2,3 | 2,5 | 3,7 |
| | 2008 | 981 145 891,1 | 2,3 | 2,5 | 3,6 |
| KSIA | 2007 | 981 057 050,5 | 1,4 | 3,6 | 4,9 |
| | 2008 | 981 057 048,3 | 1,0 | 3,6 | 4,9 |
| JANO | 2007 | 981 043 668,4 | 1,8 | 1,1 | 2,2 |
| KLAD | 2007 | 981 036 426,5 | 1,7 | 1,1 | 2,2 |
| LUBI | 2007 | 981 177 942,4 | 1,5 | 0,7 | 1,9 |
| KACI | 2008 | 980 843 150,3 | 1,6 | 1,8 | 2,9 |
| NIED | 2008 | 980 855 669,0 | 1,6 | 1,2 | 2,3 |
| LACK | 2008 | 980 892 800,2 | 1,5 | 2,8 | 4,0 |

## 3. DEFINITION OF GRAVITY REFERENCE LEVEL

**In order to guarantee unify gravity reference level for all (past and present) g determinations FG5-230 unit took part in two comparison meetings :**

**Local Calibration at Pecný (FG5-215) and Bad Hamburg (FG5-301) stations in 06/2006 – determined bias for FG5-230 reference to ECAG'2003 level was +1,0 µGal ± 0,2 µGal (Barlik et al.,2009);**

**ECAG Meeting in Walferdange (Luksemburg) in 2007 - 21 absolute gravimeters have been calibrated in underground Laboratory for Geodynamic, Centre for Geodynamics and Seismology (ECGS) for three 24-hours sessions. The reference level for FG5-230 system comparing to ECAG2007 level is + 0,1 µGal ± 0,9 µGal (Francis, 2008) (see fig. 2) ;**

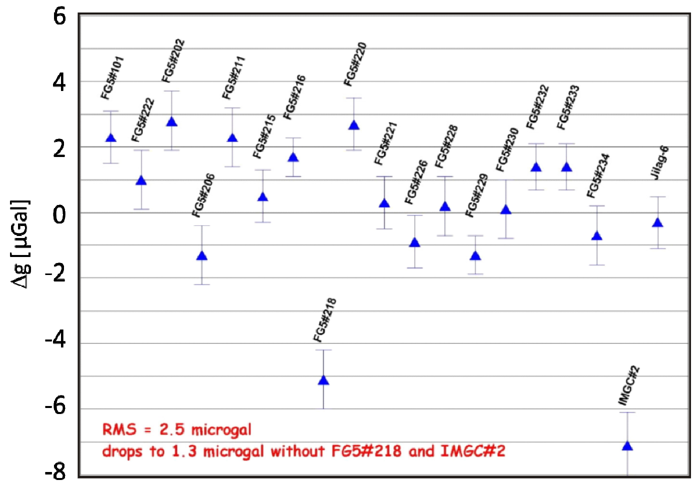


**Fig. 2. Calibrations result for ECAG2007 (Francis, 2008).**

## 4. GRAVITY REFERENCE FRAME FOR IGS/EPN STATIONS

**Absolute gravity determinations were carried out at seven points established near permanent GNSS stations in two observation campaigns (2007 and 2008). Four of them, near IGS stations (BOGI, BORO, JOZE and LAMA) have been included in Zero-Order Polish Fundamental Gravity Network in 90's. At these points gravity values were determinated using few models of absolute gravimeters (except JOZE stations where only measurements were taken by FG5-230 unit). Figures 3-6 shown g value at these stations (gray squares refer to g value determinated within a framework of this project).**

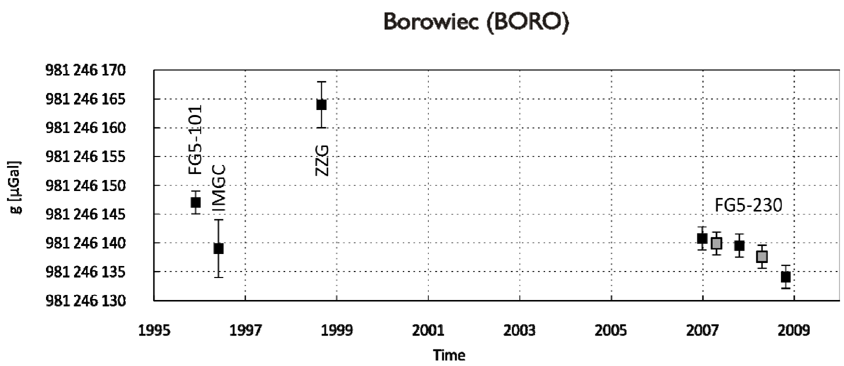


**Fig. 3. Absolute g value at Borowiec station.**

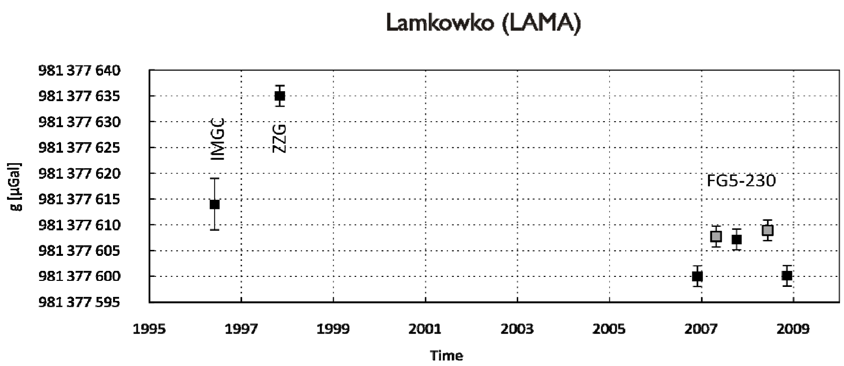


**Fig. 4. Absolute g value at Lamkówko station.**

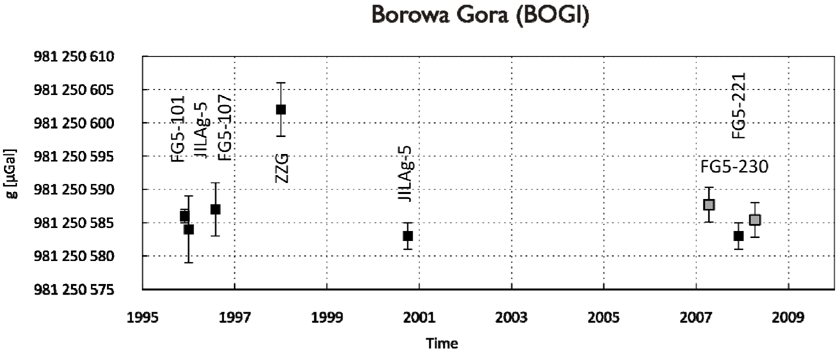


**Fig. 5. Absolute g value at Borowa Gora station.**

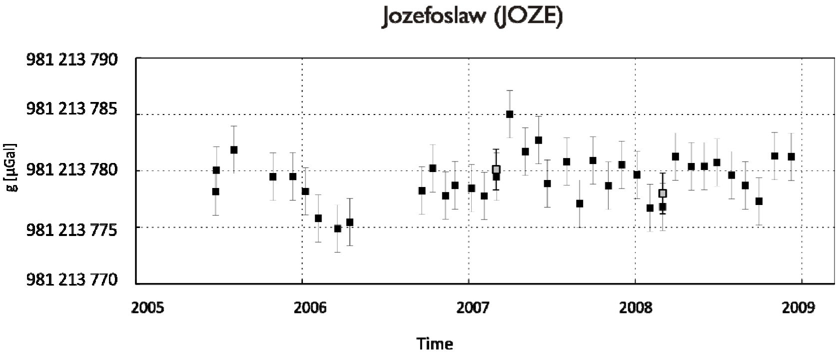


**Fig. 6. Absolute g value at Jozefoslaw station.**

**It is easy to observe that values of gravitational acceleration were slightly decreased for points located in the centre of Poland (JOZE and BOGI), in the vicinity of Warsaw and its suburbs. On the other points the gravitational acceleration values were increased from 1.5 µGal in Lamówko to 4 µGal in Kraków (see Tab. 1). From 2007 to 2009 at two stations (BORO and LAMA) g value determinations were taken five times by the same absolute apparatus (FG5-230). These results of g determinations were compared to IGS stations coordinates ( N, E, H components). Figures 7 and 8 show coordinate time series at BORO and LAMA stations with marking (vertical solid lines) g measurement epochs. On the basis of these figures one can find that changes of g values at BORO and LAMA stations aren't correlate with coordinates changes (height component).**

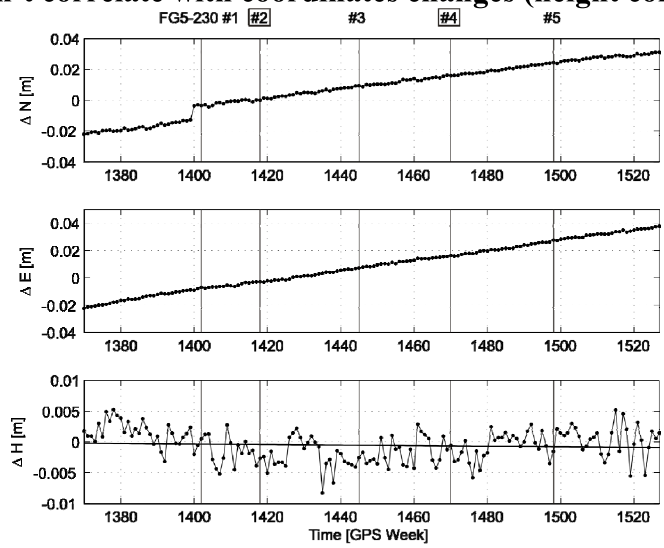


**Fig. 7. Time series of coordinate components at BORO IGS station (vertical solid lines mark g measurements epoch).**

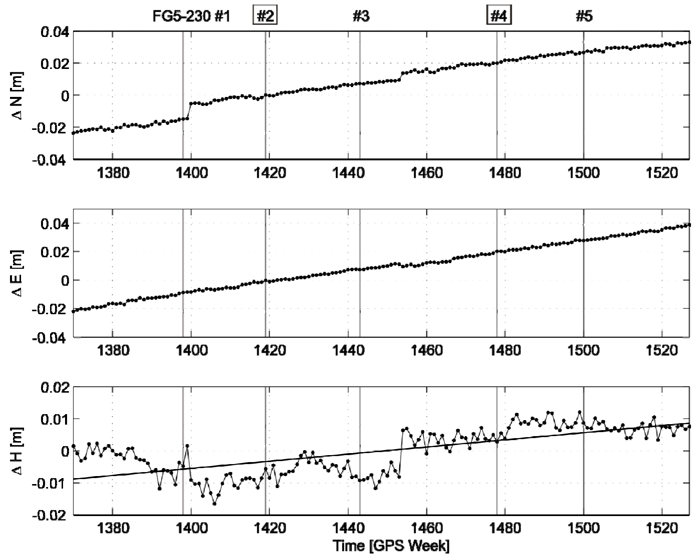


**Fig. 8. Time series of coordinate components at LAMA IGS station (vertical solid lines mark g measurements epoch).**

**Taking into account the mean errors in acceleration evaluation, which are on the level of 2 µGal, these changes do not exceed limit errors of acceleration evaluation. Therefore, the gravitational acceleration values, obtained from two measuring epochs, should be treated as output values for further studies.**

## 5. GRAVITY REFERENCE LEVEL FOR GEODYNAMICAL TEST FIELDS

**The main goals of establishment of absolute gravimetric network at the geodynamic test fields areas can be summarized in a few points:**

- **unify reference gravity level for all geodynamic test fields;**
- **possibility of reference level determination at geodynamic measurement epoch;**
- **possibility of recovering reference level in case of destroying reference point;**
- **possibility of determining scale factor for relative gravimeters;**
- **high accuracy of g value at reference point – additional geodynamic information.**

**On Poland territory main geodynamic investigations are localized in the mountain regions. In the frame of project of Unified Gravimetry Reference Frame on the area of two important geodynamic test fields six absolute gravity points were established.**

### Pieniny Test Field

**The Test-field of the Pieniny Klippen Belt (PKB) is situated in Southern Poland close to the Polish/Slovak border. Geodynamic studies of this area were performed continuously from early sixties of the last century until 2004 (Ząbek et al.,1988; Czarnecki et al.,2004). Diversified vertical motion (on the level of some mm/year) and horizontal displacements (reaching 10 mm/year) were proved (Czarnecki et al.,2004). The additional factor which can increase geodynamical activity is the dam on Dunejc River and the artificial lake between Niedzica and Czorsztyn which were put into use in 1997. Figure 9 shows location of absolute gravimetry stations on test field area.**

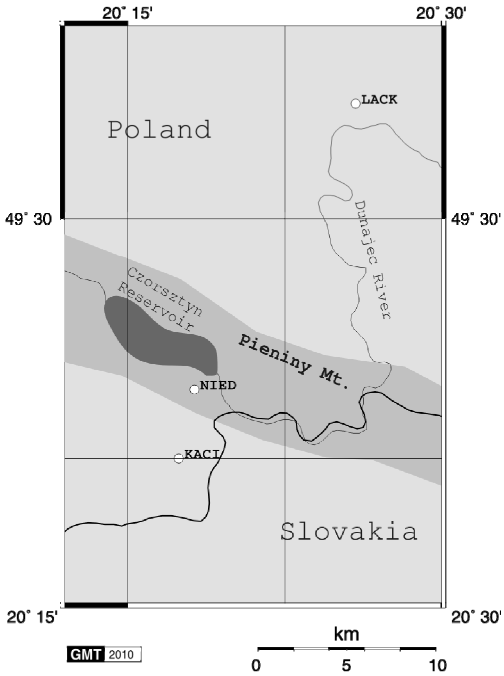


Fig. 9. Pieniny Test Field.

## Sudetes Test Fields

**Geodetic test field in Sudetes region was created by Department of Geodesy and Photogrammetry Agricultural University of Wroclaw to monitoring geodynamical behavior Fore - Sudetic Block. It consists of GNSS stations as well as gravimetric points. The first gravity measurements cycle took place in 1992 and related to the region of the Śnieżnik Massif and the Paczków Graben. Over the ten years the network became larger involving, by 2003, 78 points which were observed on a yearly basis (More information in Kątny, 2003). Gravimetric measurements were carried out only by relative gravitymeters (i.e. LaCoste&Romberg). In 2007 precise absolute determinations were carried out at five stations in the region of Sudetes Test Fields. Location of established absolute stations against a background of test fields are presented in figure 10.**


Fig. 10. Sudetes Test Fields.

## 6. UNIFIED REFERENCE LEVEL VS. POLISH GRAVITY NETWORK POGK

**The realization of Unified Gravity Network caused that two gravity reference levels, Level ABS realized by absolute gravimeter FG5-230 ( ECAG2007 level) and Level POGK established by Polish Fundamental Gravity Network were performed on Poland territory. Table 2 shows differences of g value at POGK points obtained in two ways: constrained to absolute stations (ABS Level) and network adjustment in 1998 (POGK Level). This comparison relate to points in mountain area where differences between this reference levels are bigger than in a lowland area and it is easy to observe that it cannot be neglect by referring a relative gravimetry measurements.**

**Tab. 2. Differences between Unified Reference Level and POGK gravity reference level.**

| Span | $\Delta g$ span [mGal] | $\Delta g_{Level\ ABS-POGK}$ [µGal] |
|---|---|---|
| KLOD ABS - Kłodzko POGK | 5,1519 | +42 |
| KLOD ABS - Ząbkowice POGK | 36,4787 | +37 |
| LUBI ABS - Nowa Wieś POGK | -39,4491 | +14 |
| JANO ABS - Kamienna G. POGK | -7,3413 | -39 |
| JANO ABS - Bolków POGK | 42,4204 | -4 |

## 7. CONCLUSIONS

**The primary purpose of the project, which was to establish a Uniform Reference Frame for Polish GNSS stations and Geodynamic Test Fields, has been achieved. Evaluated values of gravitational acceleration are characterized by low mean errors and differences between epochs are small and range from 1.5 to 4.5 µGal. On the basis of obtained results it should be said that:**

- **the preliminary results of observations should be still reviewed for systematic errors or influences (i.e. changing g value at BORO or LAMA station);**
- **results of calibration in 2007 in Walferdange, Luxembourg shall be taken into consideration in the final results. This will allow to control Polish Fundamental Gravity Network with European gravimetric reference level;**
- **the gravimetric measurements should be continued in the next years. This will allow to monitor changes of altitudes of network points with a higher accuracy and reliability.**

## REFERENCES

Czarnecki K.: Badania geodynamiczne pienińskiego pasa skałkowego. Monografia pod redakcją K. Czrneckiego. Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa, 2004.

Ząbek Z., Barlik M., Margański S., Pachuta A., Wojciechowski J.: Geodynamical investigations in the Pieniny Klippen Belt. Poland, from 1978 to 1985. Acta Geoph. Polonica, Vol. XXXVI, 1988.

Barlik M., Olszak T., Pachuta A., Próchniewicz D.: Badanie długookresowych zmian absolutnego natężenia siły ciężkości na głównych jednostkach tektonicznych na terytorium Polski w okresie 2006-2009. Oficyna Wydawnicza Politechniki Warszawskiej, 2009.

Francis O, Dam van T. et al: Results of the European Comparison of Absolute Gravimeters in Walferdange (Luxembourg) of November 2007. Presented on IAG International Symposium Gravity, Geoid and Earth Observation 2008, Chania, Greece, 23-27 June 2008.

Kątny B.: Geodezyjne badania współczesnej kinematyki głównych struktur tektonicznych polskich Sudetów bloku przedsudeckiego na podstawie pomiarów GPS. Zesz. Nauk. AR Wroc., Nr 468, Rozprawy, 2003.