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New gravity control in Poland – needs, the concept and the design

Jan Krynski[1], Tomasz Olszak[2], Marcin Barlik[2], Przemyslaw Dykowski[1]

[1] Institute of Geodesy and Cartography
Department of Geodesy and Geodynamics
27 Modzelewskiego St., 02-679 Warsaw, Poland
e-mail: jan.krynski@igik.edu.pl; przemyslaw.dykowski@igik.edu.pl

[2] Warsaw University of Technology
Department of Geodesy and Geodetic Astronomy
1 Plac Politechniki, 00-661 Warsaw, Poland
e-mail: t.olszak@gik.pw.edu.pl; mbarlik@gik.pw.edu.pl

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Abstract: The existing Polish gravity control (POGK) established in the last few years of 20th century according to the international standards is spanned on 12 absolute gravity stations surveyed with four different types of absolute gravimeters. Relative measurements performed by various groups on nearly 350 points of POGK with the use of LaCoste&Romberg (LCR) gravimeters were linked to those 12 stations. The construction of the network, in particular the limited number of non homogeneously distributed absolute gravity stations with gravity determined with different instruments in different epochs is responsible for systematic errors in g on POGK stations. The estimate of those errors with the use of gravity measurements performed in 2007-2008 is given and their possible sources are discussed.

The development of absolute gravity measurement technologies, in particular instruments for precise field absolute gravity measurements, provides an opportunity to establish new type of gravity control consisting of stations surveyed with absolute gravimeters. New gravity control planned to be established in 2012-2014 will consist of 28 fundamental points (surveyed with the FG5 – gravimeter), and 169 base points (surveyed with the A10 gravimeter). It will fulfill recent requirements of geodesy and geodynamics and it will provide good link to the existing POGK. A number of stations of the new gravity control with precisely determined position and height will form the national combined geodetic network.

Methodology and measurement schemes for both absolute gravimeters as well as the technology for vertical gravity gradient determinations in the new gravity control were developed and tested. The way to assure proper gravity reference level with relation to ICAG and ECAG campaigns as well as local absolute gravimeter comparisons are described highlighting the role of metrology in the project. Integral part of the project are proposals of re-computation of old gravity data and their transformation to a new system (as 2nd order network) as well as a definition of gravity system as "zero-tide" system. Seasonal variability of gravity has been discussed indicating that the effects of environmental changes when establishing modern gravity control with absolute gravity survey cannot be totally neglected.

Keywords: gravity control, absolute gravity determination, local hydrology

1. The existing Polish gravity control (POGK)

The existing Polish gravity control (POGK) has been established in 1994-1997 (Sas-Uhrynowski et al., 1999, 2000) according to the international standards determined by the International Gravimetric Commission (ICG) (Boedecker, 1988). It is based on only 12 absolute gravity stations, 1 in 26 000 km^2 (following the strictly recommended by ICG one station per 15 000 km^2, there should be 20 absolute gravity stations in POGK). They were surveyed with four different types of absolute gravimeters (FG5, JILAg, IMGC, and ZZG) by the teams from Finland (Finnish Geodetic Institute), Germany (Institut für Angevandte Geodäsie), Italy (Istituto di Metrologia), Poland (Warsaw University of Technology), and the United States (Defense Mapping Agency). Relative measurements on 363 points (1 in 870 km^2) performed by various groups with the use of LaCoste&Romberg (LCR) gravimeters were linked to those 12 absolute gravity stations (Figure 1). At each absolute gravity station vertical gravity

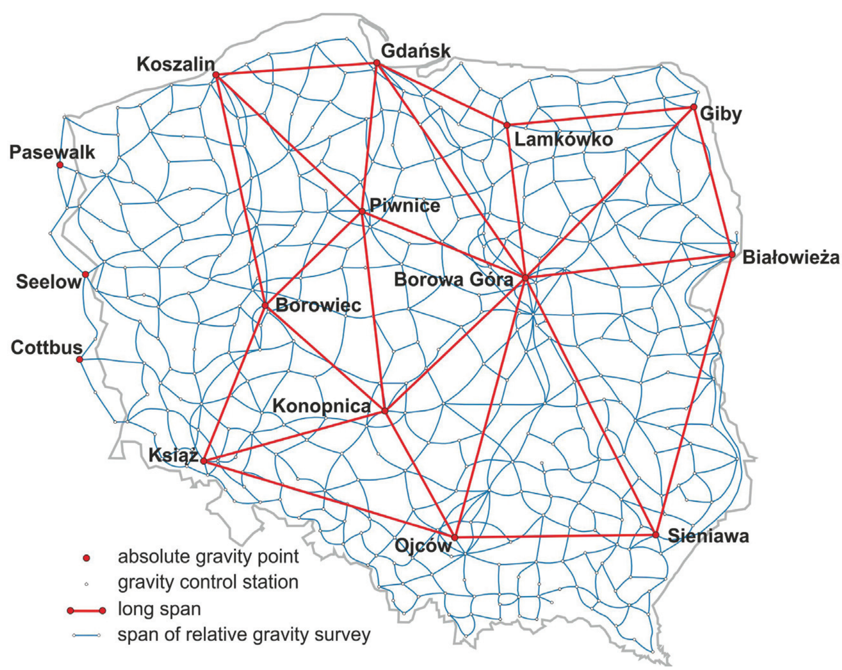

Fig. 1. Polish gravity control (POGK) 1994-1997

gradient was determined from the measurements with a set of spring gravimeters at two levels (usually one meter apart). After reducing the measured gravity at absolute gravity stations to the benchmark level, the gravity control network (Figure 1) has been adjusted with fixed 12 described above absolute gravity stations and 3 absolute gravity points in Germany (Cottbus, Pasewalk, Seelow). A network of 24 long spans connecting absolute gravity stations, surveyed with LCR gravimeters with the use of strategy developed at the Institute of Geodesy and Cartography (IGiK), Warsaw, was established to verify the consistency of absolute gravity measurements (Krynski et al., 2003).

The POGK was the basis of an extensive analysis and unification of gravity data from the area of Poland that resulted in developing local quasigeoid models of a centimetre accuracy and their reliable evaluation (Krynski and Lyszkowicz, 2006, 2007; Krynski, 2007).

Maintenance of gravity control was traditionally performed with spring gravimeters calibrated on calibration baselines. Two gravimetric calibration baselines: Central Gravimetric Calibration Baseline, and Western Gravimetric Calibration Baseline spanned on absolute gravity stations and consisting of gravity control network points became thus an integral part of POGK.

Systematic modernization of the Polish gravity control, including gravimetric calibration baselines, started already in 1999 (Barlik et al., 2010). 20 new absolute gravity stations were surveyed with the FG5 gravimeters – 18 with the FG5-230 of the Warsaw University of Technology (WUT): 5 for network densification (1 in 18 500 km^2); 7 for Central Gravimetric Calibration Baseline; 4 for Western Gravimetric Calibration Baseline; and 2 for newly established Vertical Gravimetric Calibration Baseline in Sudety Mountains; and – 2 with the FG5-221 of the Finnish Geodetic Institute (FGI) for newly established Vertical Gravimetric Calibration Baseline in Tatra Mountains. Also 2 new network points were established. New stations were linked with the gravity network by means of 14 spans measured with LCR gravimeters. In addition, 13 new long spans connecting 2 new absolute gravity stations in western Poland with the remaining ones as well as absolute gravity stations close to the country borders with the neighbouring 3 in Germany, 3 in Czech Republic, and 1 in Lithuania, were measured with LCR gravimeters to verify the consistency of absolute gravity measurements in the network (Figure 2) (Krynski and Rogowski, 2009).

In September 2008 the first outdoor, portable absolute gravimeter A10-020 that allows to determine gravity with high precision has been installed at the Borowa Góra Geodetic-Geophysical Observatory of IGiK (Krynski and Sekowski, 2010). Since then numerous test measurements were conducted in order to examine the suitability of the A10 gravimeter for the establishment of modern gravity control in Poland.

2. The need for the new gravity control in Poland

The extension of Polish gravity control by new absolute gravity stations as well as gravity network stations within its modernization process caused the need for re-adjustment of the modernized gravity network. On the other hand, activities towards modernization of Polish gravity control indicated at some stations substantial discrepancies between the absolute gravity of POGK and the corresponding

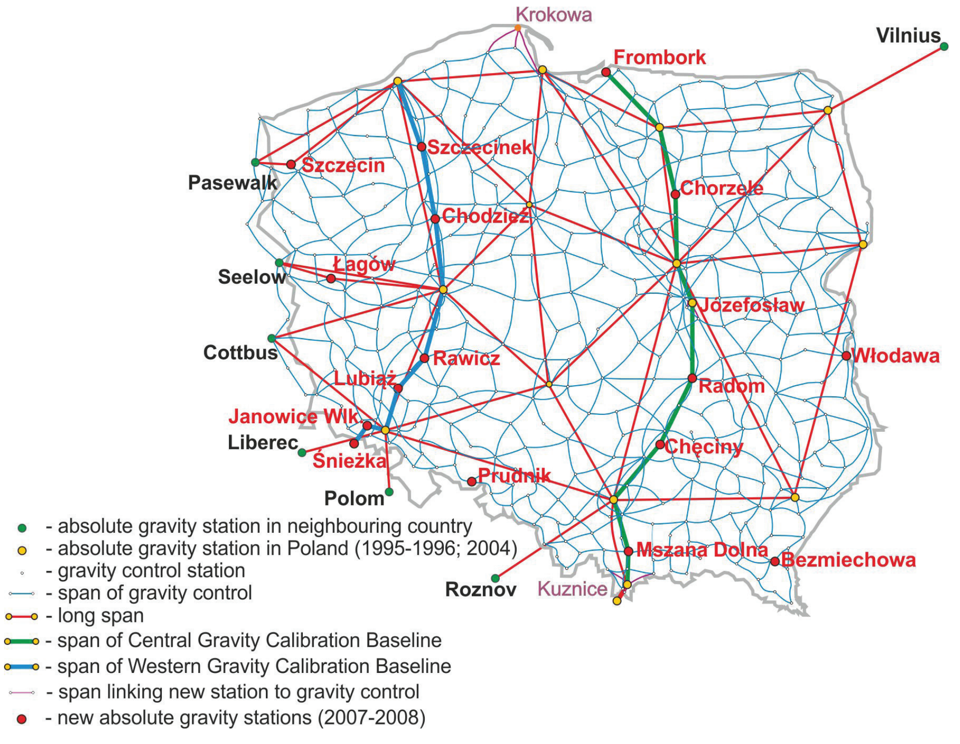

Fig. 2. Modernization of Polish gravity control (POGK) 1999-2010

ones measured with the FG5-230 in 2007-2008 (see Sec. 2.1). Moreover, field reconnaissance conducted in 2009, supplemented with visiting gravity stations when running different projects in the area, showed that almost 100 stations of existing gravity control were destroyed or not found. Recognizing the role of geodynamics in modern vertical and gravity reference systems (Krynski and Barlik, 2012) as well as the weaknesses of the existing gravity control in Poland, and simultaneously noting the development of technologies of absolute gravity survey, possibility of absolute gravity survey on field stations, the need for the establishment of new gravity control in Poland has been strongly suggested by the authors to the Head Office of Geodesy and Cartography, Warsaw, responsible for geodetic and gravity control in the country. Availability of FG5 as well as A10 absolute gravimeters and the experience gained in the gravity control re-survey with the use of FG5-230 (e.g. Walo, 2010) and A10-020 (e.g. Mäkinen et al., 2010) was also an important factor supporting that suggestion.

2.1. Differences between gravity in POGK system and more recent gravity determinations

The change of gravity on gravity stations depends on several factors connected with environment, including hydrology, geodynamics as well as equipment and methodology used. Therefore the observed changes of gravity can also be influenced by differences in vertical gravity gradient applied as new as well as old measurements were reduced to the benchmark level. Such changes were recorded when comparing gravity values obtained in 1994-1997 with the corresponding ones determined starting from 2007 during the modernization of the Polish gravity control. The example of such changes presenting differences of absolute gravity for four fundamental stations – Borowiec, Giby, Lamkówko and Ojców – between absolute gravity measurements with the use of different ballistic gravimeters during establishing POGK (epoch 1999) and absolute measurements of *g* in 2008 with the FG5-230 are given in Table 1.

Table 1. Difference d*g* between gravity measured with FG5-230 in 2008 on chosen fundamental stations and the corresponding one in POGK99 system

Station	$dg_{\text{FG5-230 2008 – POGK99}}$ [μGal]
Borowiec	-14
Giby	-8
Lamkówko	-15
Ojców	-9

Comparison of gravity values obtained in 2008 with the respective ones defined as "reference gravity" for POGK system from 1999 shows a systematic decrease of *g* on each station. The values of gravity changes obtained are much larger than uncertainty of gravity determination with ballistic gravimeters. Their rate of change reaches 1.5 μGal/year in northern Poland. They have been interpreted in terms of geodynamic and hydrological phenomena (Barlik et al., 2009a).

Low number of absolute gravity stations, limited to 12, on which the POGK with its relative gravity measurements has been spanned caused substantial systematic errors in POGK, especially in southern, mountainous area of Poland. It is connected with problems concerning the determination of scale factor of relative gravimeters when surveying the stations beyond the area determined by the existed in 1999 absolute gravity stations. This problem has been solved by establishing two vertical gravimetric calibration baselines in southern Poland: Zakopane-Kuźnice-Kasprowy Wierch in Tatra Mts., and Janowice-Śnieżka in Sudety Mts. (Sas et al., 2005; Barlik et al., 2008). For both vertical gravimetric calibration baselines the distance between first and last station does not exceed 15 km while the height difference and gravity difference between them are 1160 m and 250 mGal, and 1010 m and 240 mGal, respectively. After the modernization of gravimetric calibration baselines that lasted from 2004 until 2008 gravity data of the existing POGK99 system was not re-adjusted. Newly determined gravimeter's scale factors are referred to recent epoch and are not transformable to the epoch of POGK99.

Gravity differences between POGK system (1999) and values obtained during modernization of gravity control (2007-2008) on all eccentric points of absolute gravity stations are presented in Table 2. New gravity values were measured using spring gravimeters on the spans connecting new location of absolute stations with the existing POGK stations, chosen as eccentric points. The map of gravity differences based on data given in Table 2 is shown in Figure 3.

Table 2. Difference dg between gravity measured in 2007-2008 on chosen POGK stations and the corresponding one in POGK99 system

No and name of POGK station	φ [°]	λ [°]	$dg_{2007\ 2008\ -\ POGK99}$ [μGal]
49 Bobolice	53.5714	16.3509	-8
109 Torzym	52.1841	15.0422	-18
353 Łagów	52.2020	15.1750	-14
258 Prudnik	50.1914	17.3448	-22
243 Kamienna Góra	50.4648	16.0208	10
242 Bolków	50.5515	16.0617	-9
182 Nowa Wieś Legnicka	51.0915	16.1032	-11
189 Wińsko	51.2817	16.3658	-32
32 Goleniów	53.3321	14.4938	-10
16 Braniewo	54.2110	19.4046	-22
83 Chorzele	53.1509	20.5356	9
84 Przasnysz	53.1000	20.5000	0
218 Radom	51.2410	21.0724	-4
217 Skarżysko	51.1500	21.0000	-17
323 Myślenice	49.3500	20.0500	49
352 Sławatycze	51.3500	23.2500	-10
339 Miejsce Piastowe	49.3000	22.1500	37

The results presented in Table 2 and in Figure 3 show that in central and northern Poland the differences between new gravity values (2008) and the old ones (1999) do not exceed 20 μGal. Such value is accepted in terms of the requirements in POGK network concerning uncertainty of relative gravity measurements. In the area of southern Poland those differences are, however, larger; they reach 40 μGal. The values and distribution of gravity differences obtained illustrate errors connected with insufficient number of absolute gravity stations in the POGK network in its realization in 1999.

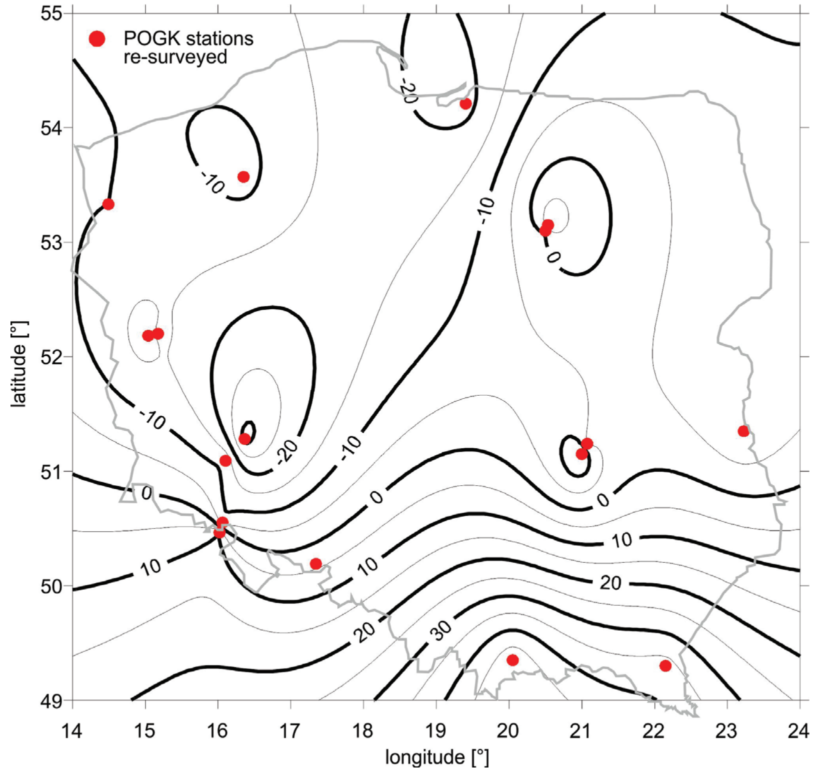

Fig. 3. Difference d*g* between gravity measured in 2007-2008 on chosen POGK stations and the corresponding one in POGK99 system [μGal]

3. Objectives of the establishment of the new gravity control in Poland

Development of technologies of absolute gravity survey in last decades, in particular portable instruments for precise field gravity measurements, allows to modify the concept of gravity control, and provides an opportunity to establish new type of gravity control consisting of stations surveyed with absolute gravimeters. The establishment and – what is extremely important – the maintenance of such kind of gravity control is more efficient than the classical one performed with the use of relative gravity measurement technique. Modern gravity control will also better fulfill the needs of contemporary geodesy and geodynamics considering temporal variations of the gravity field (Krynski, 2012).

The concept of the new gravity control should take into account and incorporate

- recent technological development,
- availability of modern high-tech instruments,
- accuracy and reliability requirements,
- assurance of efficient maintenance of gravity control.

New gravity control in Poland should assure proper gravity reference level. It should be determined by metrological procedures and parameters in relation to the International Comparison of Absolute Gravimeters (ICAG) campaigns and European Comparison of Absolute Gravimeters (ECAG) campaigns. More frequent gravity reference level should be verified by simultaneous gravity measurements with the FG5 and A10, within the so called local absolute gravimeter comparisons.

As many as possible existing POGK stations should be included in the new gravity control to link it with the historical networks and to enable an estimate gravity changes across the country. On the other hand, to build up the integrated geodetic network, as many as possible eccentric stations of the ASG-EUPOS system of GNSS permanent reference stations in Poland should be included in the new gravity control.

Gravity stations of the modern gravity control should be classified into two groups of two accuracy levels. First group consists of fundamental stations located in buildings, and surveyed possibly in one epoch (one year) with the use of FG5-type gravimeters. Second group consists of field stations – called base stations, surveyed within the extensive campaigns with the use of portable A10-type gravimeters. The suggested uncertainty level of gravity determined should not exceed 0.004 mGal at fundamental stations, and 0.010 mGal at base stations.

The average distribution of stations has been suggested as follows: one fundamental station in 15 000 km^2 and one base station in 2000 km^2. Special requirements have also been specified for the location of the stations of the new gravity control. It should ensure possibly long-term lasting of the station. It also should ensure an appropriate quality of absolute gravity measurements. All gravity control stations need a solid monumentation ensuring stability required for absolute gravity measurements and their repeatability.

At all fundamental stations the same strategies of measuring gravity as well as the determination of vertical gravity gradient should possibly be applied. Also at all base stations the measurements of gravity as well as determinations of vertical gravity gradient should be performed using possibly the same measuring strategies.

Temporal variations of gravity in the gravity control should be monitored by regular periodic re-survey of gravity control stations. Additional monitoring of those variations should be supported by the network of gravity stations equipped with superconducting (SG) gravimeters that are regularly calibrated with the use of ballistic gravimeters.

Two absolute gravimeters: the FG5-230 of WUT and the A10-020 of IGiK, along with a set of LCR gravimeters owned by both institutions are available to be used for the establishment of new gravity control in Poland.

4. Design and realization of the new gravity control in Poland

The project of the new gravity control in Poland developed in 2011 by the team of IGiK and WUT has been accepted in early 2012 by the Head Office of Geodesy and Cartography (Barlik et al., 2011). Its aim was to fulfill the objectives specified for the establishment of the new gravity control in Poland and to provide the basis for country-wide national combined geodetic network. New gravity control is to be established in 2012-2014. It will consist of 28 fundamental points (surveyed with the FG5 gravimeter) (1 in 15 000 km^2 and 7 of the gravimetric calibration baselines) and 169 base points (surveyed with the A10 gravimeter) (1 in 2000 km^2) (Figure 4). Fundamental stations consist of the existing absolute gravity stations. Base points include chosen existing POGK points (87), POLREF (9) and EUVN (5) stations, as well as eccentric stations of the Active Geodetic Network (ASG-EUPOS) of permanent GNSS reference stations (63). Fundamental stations are located in building basements, and they include most of absolute gravity stations of POGK while base stations are well monumented field stations. The uncertainty level of gravity determined should not exceed 0.004 mGal at fundamental stations and 0.010 mGal at base stations.

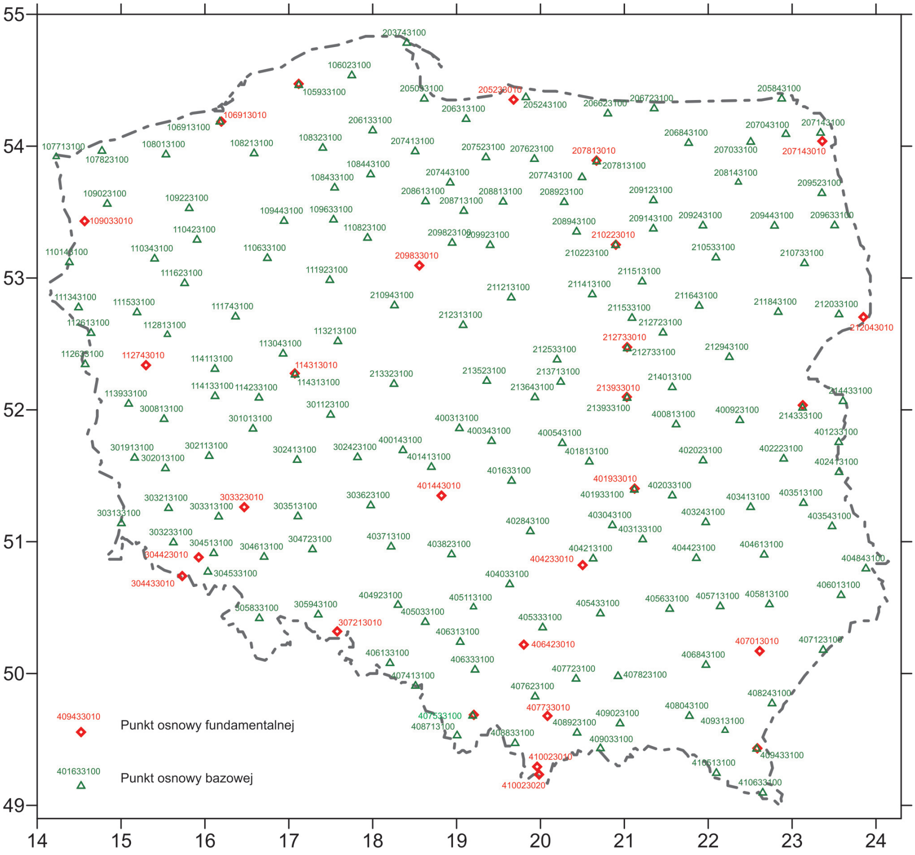

Fig. 4. New gravity control in Poland to be established within the years 2012-2014

To each fundamental station two eccentric stations are assigned: one of them possible in the vicinity of the fundamental station and the second – the closest base station. The spans of the triangle formed by the fundamental station and eccentric stations will be surveyed using spring gravimeters. The aim of eccentric stations is to provide additional control for gravity control as well as easy accessible reference for relative gravity survey in the surrounding of fundamental stations.

Both, position and height of all stations of new gravity control in Poland will be determined using GNSS technique and spirit leveling, respectively, in the national datum. The base stations with coordinates precisely determined using appropriate static GNSS survey (class B level according to EUREF) will be included into the national combined geodetic network.

Methodology and measurement schemes for both gravimeters as well as the technology for vertical gravity gradient determinations in the new gravity control have been developed and tested. Considering differences in both monumentation and environmental conditions of fundamental stations (indoors, flat and solid surface in the closest vicinity of the marker, no atmospheric disturbances, reduced seismicity caused by human activity) and base stations (field station, rough surface in the closest vicinity of the marker, affected by atmospheric disturbances, larger effect of seismicity since closer to the traffic) different stands were designed and different strategies of gravity gradient determinations were elaborated to be applied on fundamental and base stations.

Absolute gravity determination at the fundamental station is based on the measurements of 24 series of minimum 100 drops, every 10 s each in 1h time intervals. Vertical gravity gradient at the fundamental station will be derived from two independent gravity measurements performed one after another using a spring gravimeter at 4 measurement levels (specified in centimetres) for a single survey schedule as follows: 6 – 66 – 106 – 146 – 146 – 106 – 66 – 6. Measurement levels were selected to assure accurate gravity gradient determination at the instrumental height of the FG5 gravimeter required for precise gravity determination as well as to assure accurate gravity reduction to the level of the benchmark. Special stand manufactured at WUT will be used for the determination of vertical gravity gradient at fundamental stations (Figure 5).

Absolute gravity measurement at the base station will consist of at least two independent setups, each of 8 series of 120 drops, every 1 s each in 3 minutes time intervals. Vertical gravity gradient at the base station will be derived from two independent gravity measurements performed one after another using a spring gravimeter at 6 measurement levels (specified in centimetres) for a single survey schedule as follows: 20 – 40 – 60 – 80 – 100 – 120 – 100 – 60 – 20. Measurement levels were selected to assure accurate gravity gradient determination at the instrumental height of the A10 gravimeter required for precise gravity determination (which can vary by a few centimetres depending on the type of monumentation) as well as to assure accurate gravity reduction to the level of the benchmark. Special stand manufactured at IGiK will be used for the determination of vertical gravity gradient at base stations (Figure 6) (Dykowski, 2012). Approach to vertical gravity gradient determination for both types of stations includes the typical height sensor of a LCR gravimeter (approximately 6 cm).

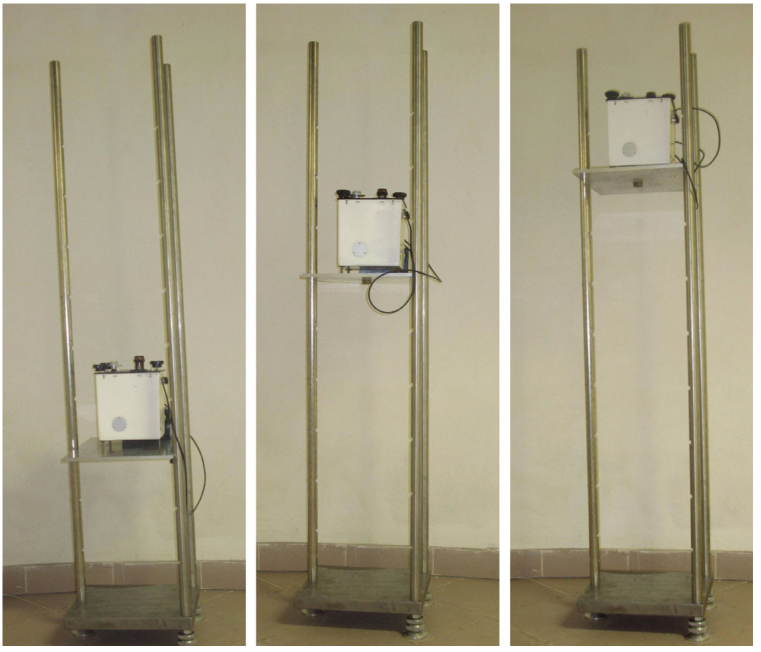

Fig. 5. The stand constructed by WUT for vertical gravity gradient determination

Fig. 6. Gravity measurements at a field station for vertical gravity gradient determination with the use of the stand constructed in the Institute of Geodesy and Cartography, Warsaw

Also the way to assure proper gravity reference level with relation to ICAG and ECAG campaigns as well as local absolute gravimeter comparisons are described. As the new gravity control will be based on absolute gravity determinations, metrology plays an especially important part of the whole project.

5. Gravity level of the gravity control in Poland

The new gravity control in Poland is not any longer a network. The spans between its stations are not expected to be surveyed with static gravimeters (except for eccentric stations). No traditional network adjustment will thus be performed since no functional link of the gravity control stations by measurements exists. The role of the adjustment is replaced by employing adequate tools of metrology to all absolute gravity surveys performed.

The gravity level of the gravity control will be determined by using free-fall FG5-type and A10-type gravimeters that participated in the international absolute gravimeter comparison campaigns organized every second year, i.e. ICAG and ECAG. Moreover, the FG5-type gravimeter should every year take part in local absolute gravimeter comparison campaign with at least one absolute gravimeter that participated in EURAMET project.

Both FG5-type and A10-type gravimeters used to survey the gravity control should, in addition, participate at least twice a year in a common comparison campaigns. The results obtained will determine a reference for relating gravity observed on base stations with gravity determined on fundamental stations.

Participation in absolute gravimeter comparison campaigns will provide an estimate of the bias of gravity determined with subsequent gravimeters and their repeatability.

Variability of metrological parameters of FG5-type and A10-type gravimeters makes it necessary to perform their calibration (verification of stability) to ensure reliable determination of gravity. Neglecting variations of metrological parameters may result in observation errors that exceed total uncertainties of the gravimeters. Both, laser and frequency standard of absolute gravimeters used to survey the gravity control should be regularly calibrated. In case of FG5 gravimeter calibration should be performed in the annual cycle while in case of A10 – at least twice a year. Calibration data of laser and frequency standard will be applied in reprocessing of gravity measurements to provide final results of survey.

Regular, periodic gravity measurements with FG5-type and A10-type gravimeters used to survey the gravity control should be repeated on monthly basis at the gravimetric laboratories equipped with the sensors recording local hydrology variations. Time series of gravity determination on the same pillars and benchmarks will provide additional control of the performance of the examined absolute gravimeters.

To keep the standard of gravity control it must be regularly re-surveyed every couple of years. It would be beneficial to run a number of stations continuously recording gravity, equipped preferably with SGs, in the area covered with the gravity control.

The integral part of the project are proposals of re-computation of old gravity data and their transformation to a new system (as 2^{nd} order network) as well as a definition of gravity system as “zero-tide” system.

6. Gravity values – static or dynamic?

Variations of gravity observed in Poland might have different sources of global and regional nature. In particular, they can reflect hydrological changes in the vicinity of gravity stations. This effect, called the environmental effect, has a significant value with respect to the uncertainty of gravity determination with the use of free-fall gravimeters, especially of the FG5-type. Regular observations of absolute gravity at Józefosław station where local hydrology is recorded (Barlik et al., 2009a, 2009b) show systematic fluctuation of *g* mainly caused by seasonal changes of amount of water in adjacent of gravity stations.

6.1. Influences of global hydrology changes on the observed gravity

The problem of the influence of continental water storage of gravity measurement emerged in last decade when the accuracy of gravimeters and accessibility of environmental data allowed for detection and modelling this effect (van Dam et al., 2001). Presently, this effect can be detected with absolute gravimeters (Rajner et al., 2011). It also can be modelled using WorldGAP Hydrology Model (WGHM) output (Döll et al., 2003) This conceptual model gives the sum of all kind of water in hydrosphere, i.e. canopy, snow, soil-water, groundwater, surface water (rivers, lakes, wetlands, inundation areas). The model has global coverage with spatial resolution of 0.5° and is issued in monthly intervals. The information on water mass distribution given in WGHM in terms of water thickness equivalent *H* along with water density *ρ* convolved with appropriate Green's function *G* can be integrated. Gravitational effect of global hydrology *L* at the point of a geocentric radius *r* can be expressed after Farrell (1972) and van Dam at al. (2001) as

$$L(r) = \rho \cdot \iint_{Earth} G(|r - r'|) \cdot H(r')\, dA'$$

where *dA'* is an elementary surface area of the geocentric radius *r'*.

Figure 7 presenting time series of gravity changes for selected absolute gravity stations in Poland: Borowa Góra (BOGO), Józefosław (JOZE), Lamkówko (LAMA), Zakopane (ZAKO) for the period of 2009 shows the range of the hydrology loading impact on gravity.

For different localization of stations in Poland the results are very similar to those shown in Figure 7. Amplitudes of the changes reach 1.5 μGal. For Poland, the changes in continental water storage are climate driven with maximum in early spring and minimum in late summer. The analysis of GRACE data shows that equivalent water height variations on the area of Poland reach minimum in September and maximum in March. Those variations correspond to seasonal changes in geoid heights within the range of 2 mm (Kloch-Glowka et al., 2013). Progress in monitoring Earth's gravity field initiated by satellite missions GRACE and GOCE can strengthen of role global hydrology models in modelling gravity observations.

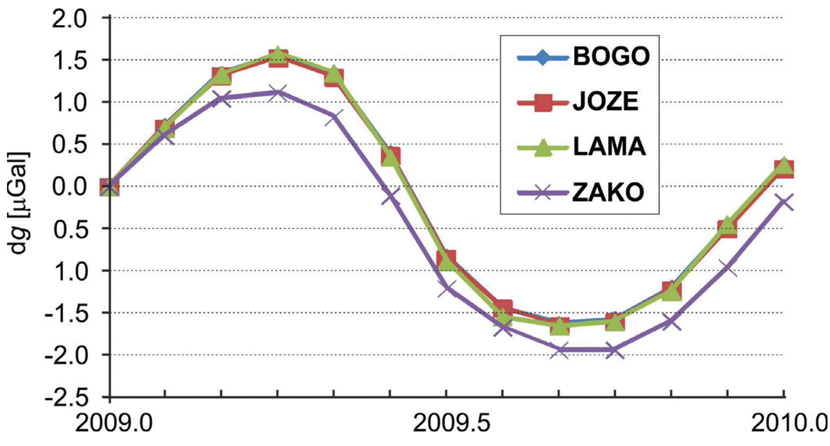

Fig. 7. Gravitational effect of global hydrology *L* for selected fundamental stations of Polish gravity control

6.2. Influences of local hydrology

Only two Polish gravity stations Borowa Góra (A10) and Józefosław (FG5) provide quasi-permanent gravity observations on monthly basis. On both stations strict relation between gravity and local hydrology is observed. To investigate such effect permanent observations of ground water level by one or multiple piezometers are required (Barlik et al., 2009a).

Local hydrology effect on measured gravity similarly to global hydrology effect reaches extreme values in spring and autumn. They are, however, several times bigger than those of global hydrology. The example of this effect for Józefosław absolute gravity station is presented in Figure 9. It was determined taking into account the Bouguer reduction formula and a porosity of the Earth's crust in a vicinity of gravimetric laboratory in Józefosław (Barlik et al., 2006). The following formula enables to eliminate the influence of water table changes Δh on gravity on the absolute gravity station:

$$\Delta g_{watertable}\left[\mathrm{mGal}\right] = 0.01027 \cdot \Delta h\left[\mathrm{m}\right]$$

Figure 8 shows raw observed value of gravity with a record of ground water level while corrections due to the water level change and corrected g as are shown in Figure 9.

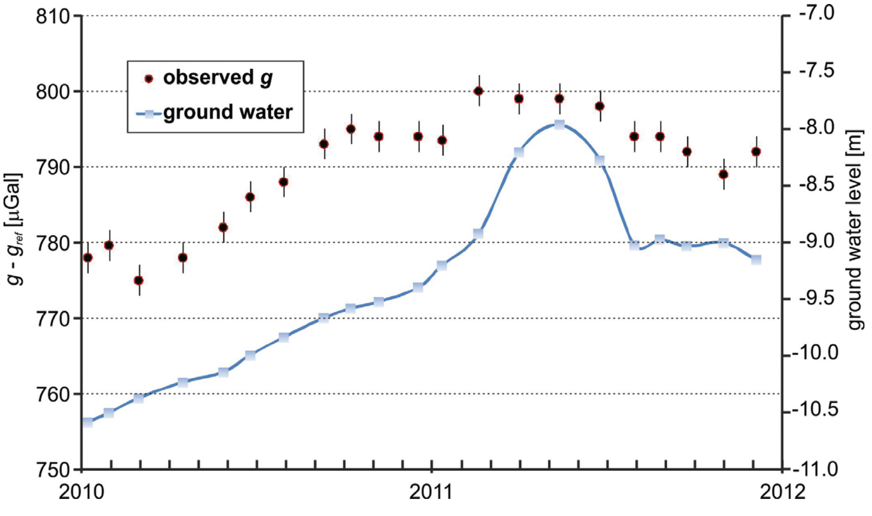

Fig. 8. Observed gravity (g_{ref} = 981213000 μGal) and water level change in Józefosław

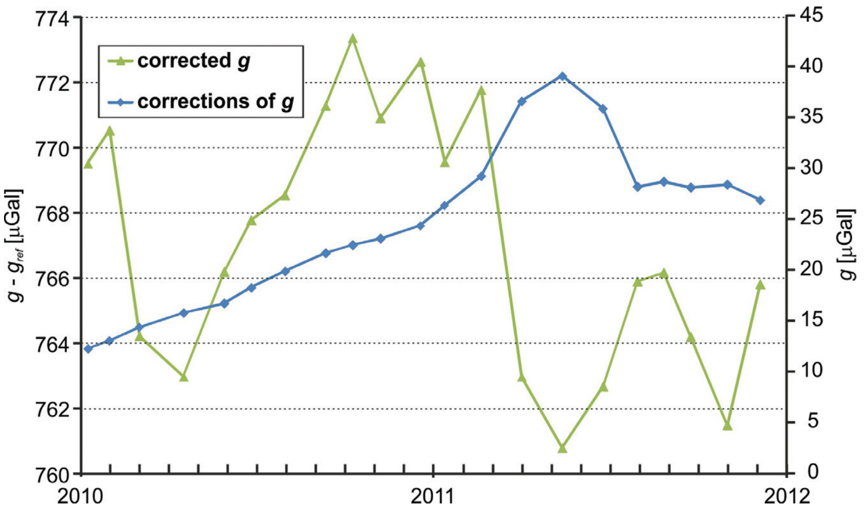

Fig. 9. Gravitational effect (g_{ref} = 981213000 μGal) of local hydrology in Józefosław

The examples illustrating the relation between only one environmental condition – seasonal global and local water fluctuations – on measured gravity shows clearly that gravity control cannot be any longer considered static. Complete understanding of the relation between gravity and local hydrological conditions in particular, requires, however, additional sensors and long quasi-permanent observations. In the works on the project concerning the new gravity control in Poland systematic effects of global hydrology on measured gravity is taken into account. Corrections related to global hydrology changes can be computed. The effect of this is expected to vary within the range of ±2μ Gal between spring and autumn. Consideration of local environmental influences on gravity on the stations with no in-site additional sensors is impossible; in such case the local effect, strictly connected with local hydrological conditions, could be extrapolated. Unfortunately the local hydrology effect on gravity is, in most cases, substantially larger than the global one.

7. Summary and conclusions

The need for the establishment of new gravity control in Poland that would fulfill present requirements of geodesy and geodynamics has been specified taking into consideration recent technical development, destruction of large number of gravity stations of the existing Polish gravity control (POGK) and the structure of POGK as well as efficiency of maintenance. Recent technical development especially concerns the availability of high-precision absolute gravimeters, in particular portable ones designed for field survey. An important factor taken into consideration was also the magnitude of gravity changes observed on POGK stations that has reached the level of several tens of microgals.

The design of the new gravity control in Poland was preceded by the extensive research that resulted in the elaboration of the objectives with consideration of local specifics. The major novelty that became the foundation of the concept of new gravity control is that it will consist of stations surveyed with absolute gravimeters but their number will be reduced by about 50% with respect to that in POGK. The role of metrology in the assurance of reliable and uniform gravity level of new gravity control has been discussed and the strategies of absolute gravity determination including vertical gravity gradient determination, and procedures of validation of absolute gravity measurements have been developed.

Special emphasis was placed on the consideration of stability of contemporary gravity control in view of the precision of recent absolute gravimeters. Presented in the paper examples show high correlation between seasonal gravity changes and hydrological conditions. The results obtained indicate that those changes can reach several microgals. This effect is dominated by local hydrology, however the systematic influence of global hydrology is also significant. Progress in monitoring Earth's gravity field initiated by satellite missions GRACE and GOCE can strengthen of role global hydrology models in modelling gravity observations. This effect must be considered when planning gravity observation campaign on the stations of gravity control. It also indicates the necessity of more frequent re-measurements of the gravity control than postulated 20 years in the Regulation of Polish Ministry of Administration and Digitalization (MAC, 2012), especially on stations of the gravimetric calibration baselines.

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Nowa osnowa grawimetryczna w Polsce – potrzeby, koncepcja i projekt

Jan Krynski[1], Tomasz Olszak[2], Marcin Barlik[2], Przemyslaw Dykowski[1]

[1] Instytut Geodezji i Kartografii
Zakład Geodezji i Geodynamiki
ul. Modzelewskiego 27, 02-679 Warszawa
e-mail: jan.krynski@igik.edu.pl; przemyslaw.dykowski@igik.edu.pl

[2] Politechnika Warszawska
Katedra Geodezji i Astronomii Geodezyjnej
Plac Politechniki 1, 00-661 Warszawa
e-mail: t.olszak@gik.pw.edu.pl; mbarlik@gik.pw.edu.pl

Streszczenie

Założona w Polsce w ostatniej dekadzie XX wieku zgodnie z obowiązującymi standardami międzynarodowymi Podstawowa Osnowa Grawimetryczna Kraju (POGK), składająca się z około 350 punktów, została oparta na 12 absolutnych punktach grawimetrycznych, na których przyspieszenie siły ciężkości wyznaczono przy użyciu czterech różnych typów grawimetrów absolutnych. Względne pomiary grawimetryczne na punktach tej osnowy, z jednoczesnym dowiązaniem jej do przyspieszenia siły ciężkości na 12 absolutnych punktach grawimetrycznych, wykonały różne grupy pomiarowe przy wykorzystaniu grawimetrów LaCoste&Romberg (LCR). Konstrukcja powstałej sieci grawimetrycznej, w szczególności ograniczona liczba nierównomiernie rozłożonych punktów absolutnych na terenie kraju, na których w dodatku przyspieszenie siły ciężkości wyznaczono różnymi instrumentami w różnych epokach, spowodowały wystąpienie błędów systematycznych w wartościach *g* na punktach POGK. W niniejszej pracy, przy wykorzystaniu pomiarów grawimetrycznych wykonanych w latach 2007-2008 dokonano oceny tych błędów oraz przeprowadzono dyskusję ich możliwych źródeł.

Rozwój technologii absolutnych pomiarów grawimetrycznych, w szczególności instrumentów przeznaczonych do precyzyjnych absolutnych pomiarów grawimetrycznych w warunkach polowych, stwarza możliwość założenia nowego typu osnowy grawimetrycznej, składającej się ze stacji, na których przyspieszenie siły ciężkości jest pomierzone grawimetrami absolutnymi. Nowa osnowa grawimetryczna Polski, która będzie zakładana w latach 2012-2014, będzie się składała z 28 punktów fundamentalnych (mierzonych grawimetrem FG5) i 169 punktów bazowych (mierzonych grawimetrem A10). Będzie ona spełniała wymagania współczesnej geodezji i geodynamiki oraz zapewniała dobre powiązanie z istniejącą osnową POGK. Znaczna liczba punktów nowej osnowy grawimetrycznej, o precyzyjnie wyznaczonej pozycji wysokości utworzy krajową zintegrowaną osnowę geodezyjną.

Opracowano i przetestowano metodologie i procedury pomiarowe na punktach nowej osnowy grawimetrycznej dla obu grawimetrów absolutnych (FG5, A10) oraz technologie wyznaczania gradientu pionowego przyspieszenia siły ciężkości na tych punktach. Określono metody zapewnienia odpowiedniego poziomu grawimetrycznego osnowy poprzez udział grawimetrów FG5 i A10 w międzynarodowej (ICAG) i europejskiej (ECAG), a także lokalnych kampaniach porównawczych grawimetrów absolutnych podkreślając jednocześnie rolę metrologii w projekcie. Integralnymi częściami projektu są zamierzenia przeliczenia archiwalnych danych grawimetrycznych wykorzystywanych przy tworzeniu POGK i ich przetransformowania do nowego systemu (jako sieć 2 rzędu) oraz zdefiniowania nowego systemu grawimetrycznego jako systemu „zero-tide". Przeprowadzono również dyskusję zmienności sezonowej przyspieszenia siły ciężkości wskazując, że przy wyznaczaniu przyspieszenia siły ciężkości na punktach nowoczesnej osnowy grawimetrycznej wpływ zmian środowiskowych nie może być traktowany jako w pełni zaniedbywalny.