ISBN 83-916216-2-6

INSTITUTE OF GEODESY AND CARTOGRAPHY

MONOGRAPHIC SERIES No 3

ANDRZEJ SAS-UHRYNOWSKI

ABSOLUTE GRAVITY MEASUREMENTS IN POLAND

Warsaw 2002

IGiK

Adres Redakcji
Instytut Geodezji i Kartografii
00-950 Warszawa, ul. Jasna 2/4
Address of the Editorial Board:
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00-950 Warsaw, Jasna 2/4 Str.
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ISBN 83-916216-2-6
IGiK, Warszawa 2002 r.
Skład komputerowy i druk: IGiK

INSTITUTE OF GEODESY AND CARTOGRAPHY

Monographic series No 3

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Reviewer:

Prof. Dr. Marcin Barlik

Key words: geodesy, gravimetry, absolute gravity measurements.

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ABSOLUTE GRAVITY MEASUREMENTS IN POLAND

ABSTRACT: New basic gravimetric network in Poland was established between 1994 and 1999. It is based on 12 points, so-called absolute points; the measurements on these points were done with five ballistic gravimeters: FG5-101, FG5-107, JILAg 5, IMGC and ZZG. Absolute points were selected, according to recommendations of the International Gravimetric Commission, on the lowest floors of such buildings, as observatories, museums, schools, churches, etc. It gives a chance, that the absolute point will survive for at least several decades. The paper includes the detailed descriptions of all absolute points. The measurements were performed by German, American, Finnish, Italian and Polish teams. As results of measurements, done with the use of various gravimeters, differed on a few points even by 30 microgals, it was necessary to make their verification. The direct connecting measurements between absolute points were performed with the use of four LaCoste & Romberg gravimeters. The measurements were done on 25 so-called long spans (160–300 km). Results of absolute determinations and results of relative connections were jointly analysed. This analysis enabled to eliminate those gravimeters, which do not fulfil the assumed criteria of reliability – IMGC and ZZG. The remaining gravimeters: FG5-101, FG5-107 and JILAg 5, which did not differ in readouts more than 3 microgals, were found to be representatives of the international gravimetric standard. Their readouts were assumed as the standard for Polish gravimetric basic network. The results of relative measurements on 685 spans of network were adjusted to 12 absolute points and to 3 points on the territory of Germany. Finally, a set of values of gravity acceleration for 354 points of network was obtained. This network is homogeneous, as far as gravimetric level and gravimetric scale is concerned; it also fulfils accuracy and construction requirements.

1. INTRODUCTION

The first gravity control network for Poland was established in the sixties (Bokun J., Sas A. 1985). After more than 30 years it does not fulfil any longer the needs of modern geodesy. In addition, the field gravity stations have not been marked. Therefore, neither densification of the network nor improvement of the accuracy of the network by repeating measurements was possible.

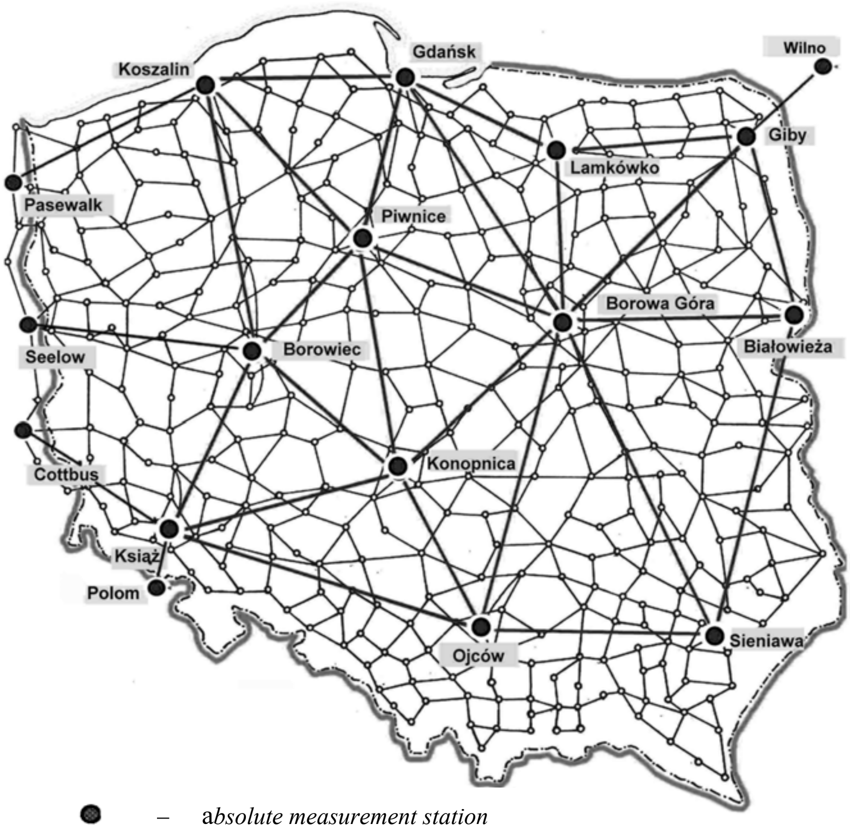
A project of a new gravity network was worked out at the Institute of Geodesy and Cartography (IGiK) in Warsaw in early nineties. The gravity survey in 1994–1998 was also performed by the initiative of IGiK (Siporski L. 1999), (Sas A. 1999), (Sas-Uhrynowski A. et al., 1999), (Sas-Uhrynowski A. et al., 2000), (Siporski L. et al., 2000). Observations were made by the teams of IGiK in collaboration with the teams of the Military Topographic Service and of the Warsaw Technical University.

The new gravity network consists of 354 points marked with concrete pillars (0.8 x 0.8 x 1.0 m) buried with upper plane on the ground level. In addition, twelve absolute gravity stations included to the network were established. They are situated, in accordance with recommendations of the International Gravity Commission (IGC) of IAG (Boedecker G. 1988), in the lowest floor of such structures like observatories, museums, universities and similar solid buildings. Two calibration lines, the Central and the Western one, were also set up. Each calibration line is based on three absolute gravity stations – two at both ends of the line and one in the middle. The scheme of the new gravity network is shown in Fig. 1.

The gravity network points are linked with 685 spans that form 313 closed figures from triangles to pentagons. The relative gravity measurements on each span were performed 3 times within one day using 3 LaCoste & Romberg (LCR) gravimeters. The mean square error computed from misclosures of the figures and from the adjustment of the network did not exceed 9 microgals (1 μGal = 10^{-8} ms^{-2}). Fig. 1 shows also the long spans between 12 absolute gravity stations. They were measured using 3 or 4 LCR gravimeters with an accuracy of ±4 μGal and were used to check the results of absolute gravity measurements.

From 1909 until 1971 the gravity networks were linked to the absolute gravity station in Potsdam where gravity was determined in 1898–1904 with a reversible pendulum (Potsdam gravity reference system). More recent absolute gravity measurements showed a systematic error of +14 μGal in the gravity value of Potsdam. Therefore, the international gravity campaign was carried on in 1950–1970 to give the basis for a new global gravity system. The International Gravity Standardization Net 1971 (IGSN71) was introduced in 1971 as the new reference system (Torge W. 1980).

Constructing of ballistic gravimeter and then its mobile versions allowed for systematic increase of the number of points with absolute gravity determined.



– *absolute measurement station*
– *span of the network*
– *long span*

Fig. 1. Gravity control network for Poland

The principle of measurements with ballistic gravimeter is simple. Time of the free falling down probe body in the vacuum chamber on the defined segment of its way is measured. The measuring procedure is however, very complicated in practice since the high accuracy of order of 10^{-9} of the measurement is required. Therefore, only a few companies in some countries such as China, France, Italy, Japan, Poland, Russia, Ukraine and USA developed ballistic gravimeter. In the USA, for example, only short series of two types of ballistic gravimeters, i.e. the JILAg and a newer one the FG5 have been manufactured. Totally, about 20 devices have been built. Only 3 or 4 organisations owing the gravimeters conduct gravity survey out of their countries. Nevertheless, up to date the absolute gravity measurements were already performed at some hundreds of stations and their number increases.

IGC is at present responsible for defining the global gravity system. Gravity standard, in accordance with the IGC recommendations, is represented by a set of gravity values determined using ballistic apparatus (absolute gravimeters) that were calibrated during the International Comparison Campaign in Sèvres, France. Therefore, in order to establish a modern gravity control each country aims to set up a number of stations with absolute gravity determined using the ballistic gravimeter tested in Sèvres.

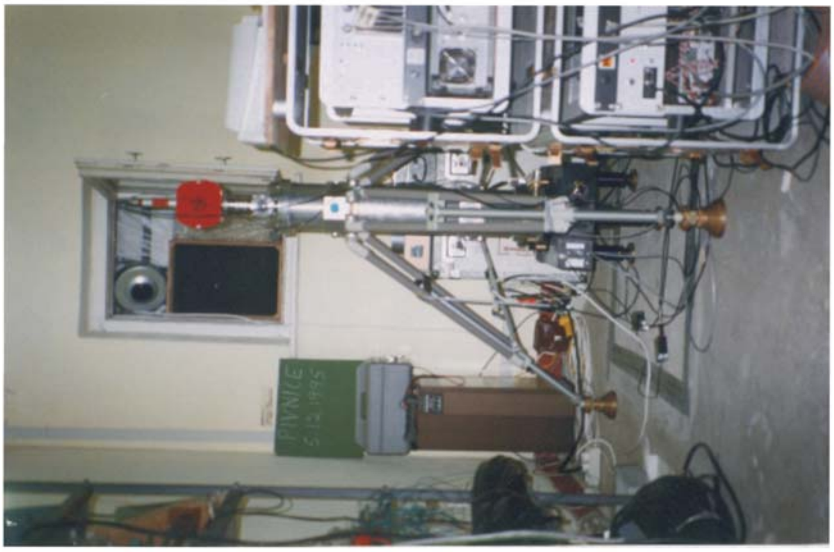
First absolute gravity measurements in Poland were conducted by the team from Novosibirsk division of the Russian Academy of Sciences supervised by Dr. Arnautov, with use of a self-made GABLE gravimeter. In 1978, the measurements were made at the Borowa Góra Geodetic-Astronomical Observatory (later named the Geodetic-Geophysical Observatory) of IGiK near Warsaw. In the same year the measurements were also made in Cracov. The next measurements were made in Gdańsk in 1986. The raw data were kept in Novosibirsk whereas only the final results were handed to IGiK.

Following the IGC recommendations the distribution of absolute gravity stations should correspond to one station per 15 000 km^2. Thus, about 20 absolute gravity stations would be required in Poland. 17 absolute gravity stations were foreseen in the project of the new gravity network – a zero-order network.

Considering the planned modernisation of the gravity network IGiK accepted in 1992 the offer of the Institute of Metrology, Kharkov, Ukraine, to perform several series of experimental absolute gravity measurements in the Polish network of zero-order using ballistic gravimeters constructed at this Institute. The aim of the project was to perform the field tests with the Ukrainian ballistic gravimeter and to examine its suitability for gravity survey of Polish gravity network. In 1992 and 1993, the measurements were conducted at 12 stations using simultaneously two ballistic gravimeters the GP-4 and GP-5. The valuable experience gained during the experimental works became very useful in the next years in both improving the apparatus and making other subsequent absolute gravity measurements in Poland.

IGiK together with the Polish Military Geodetic Service initiated in 1994 the project concerning absolute gravity measurements in Poland by foreign teams equipped with examined in Sèvres ballistic gravimeters. The goal of the project was to make at least several absolute gravity measurements at some Polish stations and to link the new gravity control network with the international gravity standard. Three foreign organizations joined the project. The former Institute for Applied Geodesy (IFAG), Germany, offered to conduct 4 measurements using the FG5 No 101 gravimeter, the Finnish Geodetic Institute (FGI) offered to conduct 3 measurements using the JILAg-5 gravimeter and the former American Defence Mapping Agency (DMA) agreed to conduct 5 measurements using the FG5 No 107 gravimeter. The pictures of the JILAg and FG5 gravimeters are shown in Fig. 2.

Ballistic gravimeter FG5



Ballistic gravimeter JILAg

Fig. 2

The co-operation with the three organisations resulted in the determination of absolute gravity at 10 following stations: Koszalin, Borowiec, Książ, Piwnice, Konopnica, Gdańsk, Białowieża, Sieniawa, Ojców and Borowa Góra. Later, in 1996, Dr Cerutti conducted the absolute gravity measurements at Lamkówko with the Italian IMGC ballistic gravimeter. He also repeated gravity measurements at Borowiec (Cerutti G. et al., 1999). At the end of 1997 and at the beginning of 1998, Prof. Ząbek measured absolute gravity at Giby and repeated observations at Lamkówko as well as at the other 4 stations including Borowa Góra with the ZZG ballistic gravimeter of his construction (Ząbek Z. 1997 and 1998).

The absolute gravity measurements were then performed using 6 various ballistic gravimeters, i.e. FG5-101, FG5-107, JILAg-5, IMGC, ZZG and GABLE that all were tested in Sèvres during the Fourth (1994) and Fifth (1997) International Comparison Campaigns. The data obtained with the GABLE was not however, taken into the analysis. The time span between the surveying campaigns with GABLE and the consecutive campaigns was considered too long. The Borowa Góra station was chosen as the fundamental point of the network. At that station the measurements have been conducted using all above-mentioned gravimeters, except the IMGC. The other five stations were surveyed using at least 2 ballistic gravimeters. Altogether, 21 absolute gravity measurements were made at 12 stations.

Among the remaining 5 stations foreseen in the project, two stations, i.e. Szczecin and Łagów are located close to the border near Pasewalk and Seelow stations in Germany. That is why the survey at Szczecin and Łagów was postponed at the time being. Last three stations, i.e. Józefosław, Św. Krzyż and Grybów have not been surveyed since they belong to the satellite geodynamic traverse (SAGET) of the Warsaw Technical University. The absolute gravity is also measured at the traverse. Those three stations do not belong to the gravity network as yet.

2. DESCRIPTION OF THE ABSOLUTE GRAVITY STATIONS

The location of the absolute gravity stations within the Polish gravity control network is shown in Fig. 3. The figure also provides information on the type of ballistic gravimeters used for measurements at the stations.

Borowa Góra. The absolute gravity station at Borowa Góra is the fundamental point of the Polish Gravity Control Network. The station is located in the Geodetic-Geophysical Observatory. The point has been established in the basement laboratory in the old building of the Observatory. The ballistic gravimeter is placed on a fixed into the floor concrete pillar of 1.0 x 1.0 x 1.5 m. The upper plane of the pillar coincides with the level of the floor.

Three other similar pillars are situated in the basement laboratory of the new building of the Observatory. One of them, called BG-Ex1 has been chosen as the first eccentric stand. Besides, there are also two pillars located in the other pavilions of the Observatory and three more pillars in the open air. One of them, named BG-Ex2 is used as the second eccentric stand. It is also the gravity control network point No 156. Two other pillars in the open air are destined for testing the relative gravimeters in the field conditions. All pillars designed for setting up the ballistic gravimeters have been built with intention to make simultaneous observations by means of several instruments both ballistic and relative ones in the aim of comparison of their readings. The geodetic co-ordinates and heights of all pillars, as well as gravity were determined (Cisak M. et al., 1998).

The first absolute measurement of gravity was conducted in 1978 with the GABLE gravimeter. Using simultaneously operating two ballistic gravimeters GP-4 and GP-5 Dr. W. Shurubkin of the Institute of Metrology, Kharkov, has surveyed gravity at Borowa Góra in 1992 and then in 1993. In November 1995, Dr. Falk (IFAG) conducted the measurements with the FG5 No 101 gravimeter (Falk R. 1996). In December 1995, Dr. Mäkinen (FGI) surveyed gravity with the JILAg-5 gravimeter (Mäkinen J. 1997). Dr. Stizza (DMA) conducted the subsequent gravity measurements with the FG5 No 107 gravimeter in July 1996 (Stizza D. 1996). At the end of 1997, Prof. Ząbek made the gravity measurements using the ZZG gravimeter. In 2000, Dr. Mäkinen repeated absolute gravity measurement with the JILAg-5 gravimeter. The results of the last survey have not been included to the adjustment that was already made earlier. They could be used to verify the result of the adjustment. In fact, the absolute gravity determined by Dr. Mäkinen in 2000 differs from the adjusted value by 4 μGal only. It confirms high quality of previous survey.

Such a long series of observations performed at Borowa Góra places this station among a few stations where absolute gravity was determined so many times with ballistic gravimeters of so various types.

Koszalin. The absolute gravity station at Koszalin is located in the Geo-technical Laboratory of the Building and Environmental Engineering Faculty of the Koszalin Technical University. The point is marked with a concrete pillar fixed into the floor on the depth of 1.5 m. The upper plane of the pillar of size of 1.0 x 1.0 m coincides with the level of the floor. The station was established in 1986. It was one of five stations of the Unified Gravity Network established within the Warsaw Treaty co-operation. In 1989, the relative gravity measurements were made using the AGAT pendulum gravimeter of the Academy of Sciences of the former USSR. The aim of the project was to link the Koszalin station with the similar stations in Poznań and in Gdańsk. In 1992, the Kharkov team made the first experimental absolute gravity measurements using two ballistic gravimeters the GP-4 and GP-5.

In 1995, Dr. Falk conducted the absolute gravity measurements with the FG5 No 101 gravimeter. KOSZ-Ex1 and KOSZ-Ex2 are two eccentric stands near the station. KOSZ-Ex1 is located at the side door to the Prof. Rzymkowski Assembly Hall. KOSZ-Ex2 situated about 2 km away is the gravity control network point No 2.

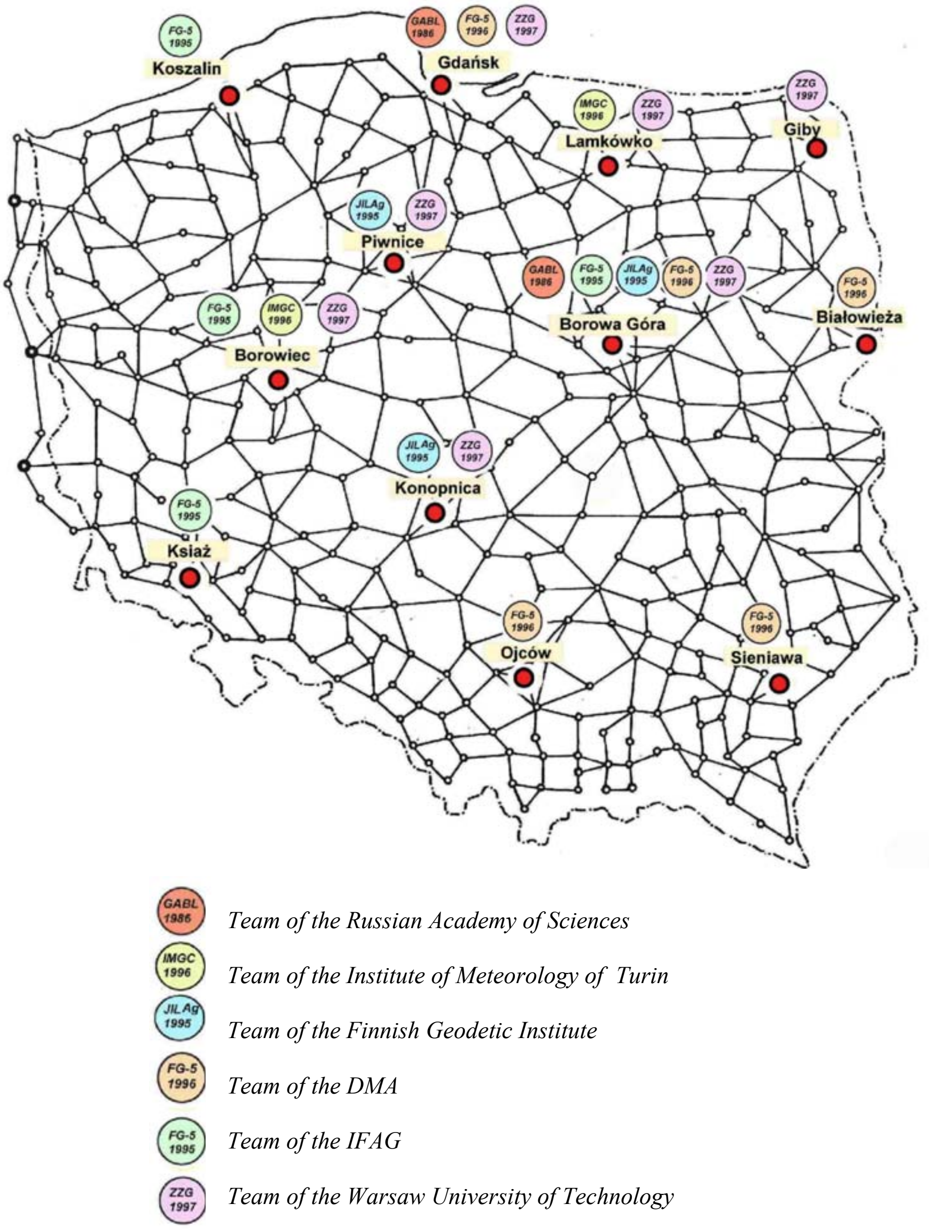


Fig 3. Location of the absolute gravity stations

Borowiec. The absolute gravity station at Borowiec is located in the premises of the Astronomical-Geodynamic Observatory of the Space Research Centre of the Polish Academy of Sciences. It is placed on the lowest floor of the main building of the Observatory in the former photo-laboratory. Initially, the location of the station was planned in the Astronomical Observatory of Mickiewicz University in Poznań, right in the centre of the town. In 1989, the relative measurements were conducted with the AGAT pendulum gravimeter at Poznań similarly to those made at Koszalin. Three years later, i.e. in 1992, the Kharkov team conducted there the experimental measurements with the GP-4 and GP-5 gravimeters. Due to high level of micro-seismicity caused by the street traffic the move of the station to Borowiec Observatory was decided.

In 1993, the experimental absolute gravity measurements at Borowiec were conducted with the GP-4 and GP-5 gravimeters. The acceptable quality of the results indicated that Borowiec could become one of the absolute gravity stations of Polish gravity control network. In November 1995, the IFAG team measured absolute gravity at Borowiec with the FG5 No 101 gravimeter. In summer 1996, Dr. Cerutti conducted gravity measurements using the Italian IMGC ballistic gravimeter. In 1998, Prof. Ząbek determined absolute gravity with his ZZG apparatus.

The station at Borowiec has two eccentric stands: BORO-Ex1 and BORO-Ex2. BORO-Ex1 is the concrete pillar (EUREF point No 216) located in the premises of the Observatory. BORO-Ex2 is fixed on the step in front of the main door to the Astrograph Pavilion.

Książ. The absolute gravity station at Książ near Wałbrzych is placed in the Lower-Silesian Geophysical Observatory of the Institute of Geophysics of the Polish Academy of Sciences. The Observatory occupies the part of the wing of the outer building of the Książ Castle. The station is situated in the left side room at the end of the cellar corridor. The point is marked with brass bolt fixed into the concrete pillar. The pillar with the upper plane of 1.0 x 2.0 m is set on the rock flush with the floor level. The Institute of Geophysics uses the Observatory for seismic investigations while the Space Research Centre carries on the Earth tides monitoring.

In 1992 and 1993, the Kharkov team conducted the series of experimental absolute gravity observations with the GP-4 and GP-5 gravimeters at Książ. In November 1995, the group of Dr. Falk measured absolute gravity using the FG5 No 101 gravimeter.

The old concrete block next to the Observatory door was chosen as a first eccentric stand KSIA-Ex1. The second eccentric stand KSIA-Ex2 is situated on the concrete step at the side door to St. Peter and Paul Church in Świebodzice.

Piwnice. The absolute gravity station at Piwnice is located in the premises of the Nicholas Copernicus Astronomical Observatory of the Toruń University. The stand is situated in the basement of the old Observatory building. The point is marked with the brass bolt fixed to the concrete pillar sank to a depth of 1.5 m. The upper plane of the pillar of 1.0 x 1.0 m coincides with the level of the floor. In December 1995, Dr. Mäkinen conducted the first absolute gravity measurements at Piwnice using the JILAg-5 gravimeter. In 1998, Prof. Ząbek measured absolute gravity with the ZZG gravimeter.

PIWN-Ex1 eccentric stand is marked with brass bolt on the concrete step in front of the Drapper Pavilion. The second eccentric stand PIWN-Ex2 is marked with the similar bolt on the concrete foundation of St John the Baptist Church in Świerzynki.

Konopnica. The absolute gravity station at Konopnica is located in the Konopnica Palace of the Technical University of Łódź that is used as the rest house. The point is situated in one of rooms belonging to the canteen in the cellar. It is marked with the brass bolt fixed into the floor of the cloakroom. In December 1995, Dr. Mäkinen conducted the first absolute gravity measurements at Konopnica using the JILAg-5 gravimeter. As the floor in the cloakroom appeared to be not enough stable the point has been moved to the next room beside the kitchen. The new point has also been marked with the brass bolt. Both points were linked by means of relative gravity measurements. In 1998, Prof. Ząbek conducted also there the measurements with his ZZG gravimeter.

The first eccentric stand KONO-Ex1 is fixed on the foundation of St. Roch Church in Konopnica. Point No 2406 of the POLREF network was chosen as the second eccentric stand KONO-Ex2.

Gdańsk. The absolute gravity station at Gdańsk is located in the Oliwa District in the premises of the Gdańsk University. The pillar for measurements is placed in the acousto-optic laboratory situated in the building of the Mathematics and Physics Faculty. The point is marked with the brass bolt in the concrete block of 1.0 x 1.0 x 1.5 m fixed into the ground with the upper plane coinciding with the level of the floor. The Gdańsk station was formerly foreseen as one of five Polish stations of the Unified Gravity Network. To link the Gdańsk station with the Russian station in Kaliningrad the absolute gravity measurements were conducted in Gdańsk in 1986 using the GABLE gravimeter and in 1987 the relative measurements with the AGAT pendulum gravimeter were made there.

In July 1996, Dr. Stizza carried on absolute gravity measurements using the FG5 No 107 gravimeter. At the end of 1997, Prof. Ząbek measured absolute gravity with his ZZG gravimeter.

GDAN-Ex1 eccentric stand marked with the brass bolt is located on the concrete foundation outside the building. The point No 11 of the gravity control network was chosen as the second eccentric stand GDAN-Ex2.

Lamkówko. The absolute gravity station at Lamkówko is located in the premises of the Satellite Observatory of the University of Warmia and Mazury about 35 km away from Olsztyn. The point is situated in the former satellite pavilion on the pillar used earlier as the stand of photographic camera for tracking satellites. The pillar was adapted to measurements with ballistic gravimeters. The upper plane of the pillar is at the height of 47 cm over the ground. The floor around the pillar has been raised to facilitate the observations. The Kharkov team conducted the experimental gravity measurements with the GP-4 and GP-5 gravimeters at Lamkówko in 1993. Dr. Cerutti measured gravity with the Italian IMGC gravimeter in summer 1996. At the end of 1997, Prof. Ząbek measured absolute gravity with his ZZG gravimeter.

The pillar in the cellar of the main building of the Observatory was used as the first eccentric stand LAMK-Ex1. The concrete mushroom-like block located in the yard of the main building is the second eccentric stand LAMK-Ex2.

Giby. The absolute gravity station at Giby is located in the premises of the parish church in Giby. The stand is situated in the cellar of the presbytery where the concrete pillar of 1.0 x 1.0 x 1.5 m has been fixed into the ground with its upper plane coinciding with the level of the floor. The first experimental absolute gravity measurements were conducted at Giby in 1993 by the Kharkov team with the GP-4 and GP-5 gravimeters. In 1997, Prof. Ząbek conducted also there the measurements with his ZZG gravimeter.

GIBY-Ex1 eccentric stand is marked with the brass bolt fixed into the concrete basement of the car repair pit outside the building. The second eccentric stand GIBY-Ex2 is the point No 29 of the gravity control network in Sejny.

Białowieża. The absolute gravity station at Białowieża is located in the premises of the Palace Park in Białowieża. At first, the stand was established in the Marshal House in the lower part of the Palace Park. The field tests made by the Kharkov team in 1993 indicated an insufficient stability of the point. Therefore the station has been moved to the building of the Department of the Mammals Investigation of the Polish Academy of Sciences. The point is situated in the fuel store in the cellar of the main building of the Department close to the local boiler-room. The concrete pillar of 1.0 x 1.0 x 1.5 m has been fixed into the ground with its upper plane at the level of the floor.

The measurements conducted by Dr. Stizza with the FG5 No 107 gravimeter in 1996 verified that the location of the new station fulfils the requirements.

Point No 171 of the gravity control network was chosen as the first eccentric stand BIAL-Ex1. The second eccentric stand BIAL-Ex2 marked with the brass bolt is a concrete step at the exit from St. Teresa Church in Białowieża.

Sieniawa. The absolute gravity station at Sieniawa is located in the Czartoryski Palace in Sieniawa recently used as a hotel (Hotel Palace) and a Conference Centre. The point is situated on the ground floor of the building (the Palace has no basement) in the small passing room to the exhibition hall. In July 1996, Dr. Stizza conducted there the absolute gravity measurements with the FG5 No 107 gravimeter.

The first eccentric stand SIEN-Ex1 is situated on the foundation of the Holy Virgin Church in Sieniawa and is fixed with the brass bolt at the main door to the church. Point No 1809 of POLREF network is used as the second eccentric stand SIEN-Ex2.

Ojców. At first, the absolute gravity station in this region has been chosen in Cracov. The stand has been situated in the cellar of the Jagiellonian University building at the Copernicus Street, in the centre of the city. The first absolute gravity measurements were made there using the GABLE gravimeter in 1978. The expansion of the city and increasing street traffic caused such big micro-seismic disturbance that no use of the ballistic gravimeter was possible. The station then have been moved to the main building of the Seismic Observatory of the Institute of Geophysics of the Polish Academy of Sciences in Ojców. One of the rooms on the ground (the lowest) floor of the building has been adapted as the gravity laboratory. The concrete pillar has been fixed on the rock with its upper plane of 1.2 x 1.2 m at the level of the floor. In July 1996, Dr. Stizza conducted first absolute gravity measurements with the FG5 No 107 gravimeter.

OJCO-Ex1 eccentric stand is situated in front of the building. It is a concrete block specially established for the project. The second eccentric stand OJCO-Ex2 has a form of the concrete block with the brass bolt fixed in the middle of its upper plane and is situated in the neighbourhood of St. Nicolas Church in Skała.

Appendix 1 *contains graphical descriptions of the absolute gravity stations listed above.*

3. ABSOLUTE GRAVITY MEASUREMENTS WITH BALLISTIC GRAVIMETERS

As it has been already mentioned the principle of gravity measurements consists in time recording of free fall of the probe body along the defined segment of its way and in measuring the length of that segment. During one fall of the body the measurements of time and distance take place in practice many times, even on several hundreds of segments. Time is measured by means of the quartz or rubidium clock with an accuracy of ±1 ns while the distance is measured by means of the laser interferometer with an accuracy of ±1 nm.

There are two approaches of measuring gravity with ballistic gravimeters. In the free-fall approach the probe body falls freely (e.g. JILAg-5 or FG5 gravimeter) in vacuum chamber. In the rise-and-fall approach the probe body is thrown vertically upward in vacuum chamber and then after reaching the apex it falls freely down (e.g. ZZG gravimeter). In this case the observations are performed when the body rises and falls. The last approach is therefore called a symmetric one while the first one is called unsymmetrical.

A survey on the stand takes at least 24 hours. It consists of 3500–4000 individual measurements in series of several dozen falls or rises and falls. The measurements are usually continued the next day when insufficient accuracy of gravity is obtained.

The measured data need to be corrected due to various factors like the drift and changes of the laser coefficients, the residual pressure in the vacuum chamber, mechanical reaction of the stand at the initial moment of the probe body movement, Earth tides, polar motion, atmospheric pressure and others.

The example of the results obtained using the FG5 No 107 gravimeter is given in Fig. 4. The graph shows the preliminary result of the survey that must be further corrected in course of the laboratory tests after the measuring campaign. The graphical presentation is suitable for fast analysis of the correctness of the gravimeter behaviour and estimation of measuring conditions, mainly the seismic ones.

Table 1 gives the examples of final results of measurements with the JILAg-5 gravimeter at Borowa Góra, Piwnice and Konopnica, i.e. the results obtained at the height of apparatus and the ones reduced to the 0.0 level (the level of the upper plane of the pillar that coincide with the level of the floor).

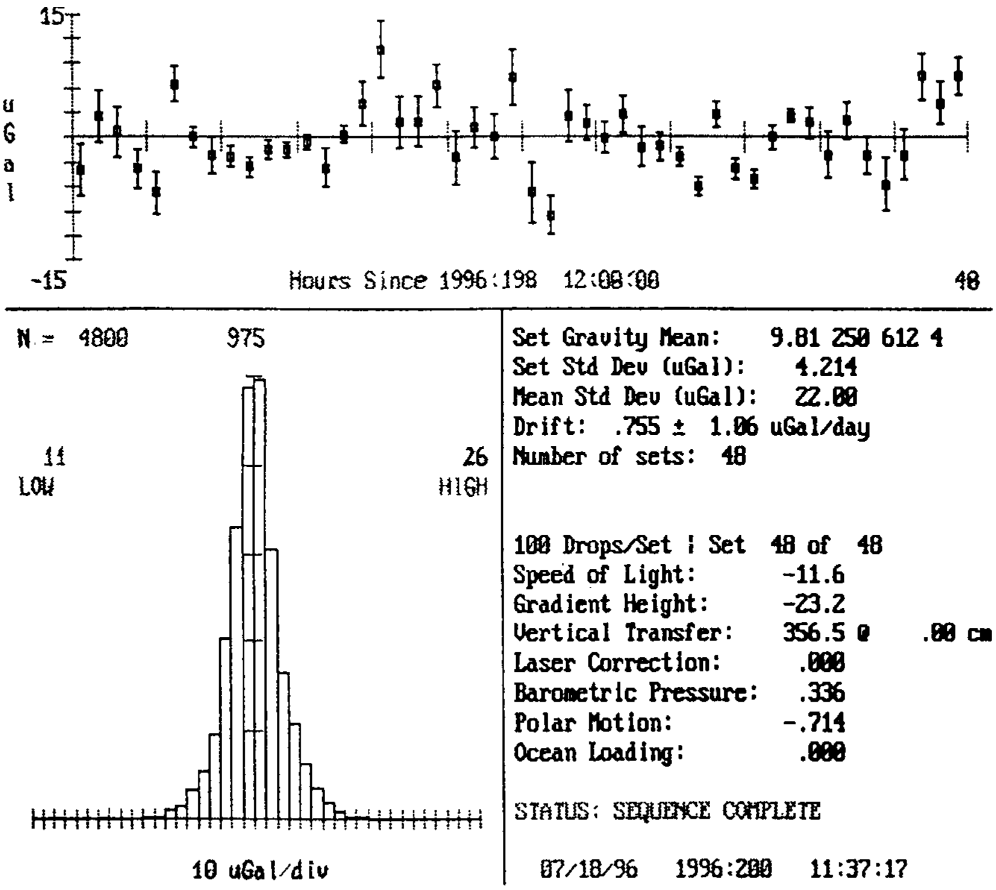


Fig. 4. Preliminary result of the absolute measurements presented graphically (Stizza – FG5 No 107)

Table 1. The final results of the absolute measurements (Mäkinen – JILAg-5)

Summary of corrections at observation height. The unit is microgal

Station	Epoch	Result at obs height with tidal	For laser drift	For frequency standart	For ZCD comparator	For recoil	For atmosphere	For polar motion	Final corrected results at obs height
Borowa Góra	24.-26.11.1995	981 250 349.7	0.1	-2.7	0.0	3.3	2.1	1.8	981 250 354.4
Konopnica	29.-30.11.1995	981 148 246.3	0.1	-2.7	0.0	2.7	4.6	2.2	981 148 253.2
Piwnice	3.-5.12.1995	981 268 445.4	0.1	-2.7	0.0	0.0	5.6	2.5	981 268 450.9

Reduction of g to different levels

Station	Final corrected result at obs height	Observation height above station mark, metres	Vertical gradient µgal/m	Reduction from observation height to 0.800 m	Result at 0.800 m	Reduction from observation height to 0.000 m	Result at 0.000 m
Borowa Góra	981 250 354.4	0.845	-271.4	12.2	981 250 366.6	229.3	981 250 583.7
Konopnica	981 148 253.2	0.847	-255.8	12.0	981 148 265.2	216.7	981 148 469.9
Piwnice	981 268 450.9	0.844	-277.6	12.2	981 268 463.1	234.3	981 268 685.2

□rror statistics. All uncertainties are one sigma, in microgals. The total uncertainty at observation height is the quadratic sum of the preceding four columns. The estimate for other systematics is from Niebauer's Ph.D. thesis (1987)

Station	Number of sets	Number of drops= =sets x 25	Rms drop scatter within sets	S.deviation of set means	S.deviation of result	Uncertainty from laser	Uncertainty from recoil	Other systematics	Total uncertainty at obs height	Uncertainty of vertical transfer	Uncertainty at 0.000 m
Borowa Góra	150	3750	27.7	4.6	0.4	3.0	3.0	2.7	5.1	2.0	5.5
Konopnica	108	2700	24.2	4.0	0.4	3.2	3.2	2.7	5.2	2.0	5.6
Piwnice	152	3800	24.9	4.2	0.3	3.0	3.0	2.7	5.1	2.0	5.5

4. GRAVITY MEASUREMENTS AT THE ECCENTRIC STANDS

In accordance with the IGC recommendations at least two eccentric stands in the vicinity of the absolute gravity station should be established. They are necessary to control and to estimate the gravimetric stability of the absolute gravity station. Such a control can be executed by repeated link measurements using relative gravity observations between all three points (main station and eccentric stands).

To follow the recommendation mentioned above and to reduce the project expenses the eccentric stands have been chosen on the existing already solid structure like a concrete step, a part of the building foundation, a concrete socle or similar objects located not far away from the main station. In several cases, the existing points of the gravity control network or the points of EUREF or POLREF networks have been used.

The three points, i.e. main absolute gravity station and two eccentric points have been linked by traverses by means of relative gravity measurements conducted using three LCR gravimeters. The vertical gravity gradient has also been determined on each stand.

5. VERTICAL GRAVITY GRADIENT

The absolute gravity point to which a defined gravity value is attributed physically corresponds to the upper plane of the concrete pillar, i.e. the level of the floor. Measurements with ballistic gravimeters are referred however, to a certain height over the point. The vacuum chamber inside which the probe body falls is set up on the tripod at a certain vertical distance from the top of the pillar. This height differs for different types of gravimeters. In both JILAg-5 and FG5 gravimeters the measurements are referred to the height of about 130 cm. In the GP device this height is about 80 cm while in the ZZG it equals 32 cm only. Gravity increases in average by 300 μGal per 1 m with decreasing height. Therefore it is necessary to determine the height of observations with millimetre accuracy and a vertical gradient with possibly high precision. Precise gravimeters were not available during absolute gravity measuring campaigns in 1978 and 1986. Determinations of gradients at Borowa Góra, Cracov and Gdańsk were not accurate. In 1995 and 1996, the foreign teams involved in absolute gravity survey in Poland were equipped with a couple of LCR gravimeters with a feedback. Such equipment provides measurements with an accuracy of ±3 μGal.

At each absolute gravity station the foreign teams measured the vertical gradient using 3 gravimeters. In 2000, the team of IGiK determined the gradient at all eccentric stands and repeated the determination of the gradient at the main absolute gravity stations with use of 2 gravimeters. At each point the gravity gradient was determined as an average of four observations.

The list of vertical gradients at the absolute gravity stations and at the eccentric stands is compiled in Table 2.

Table 2. The vertical gradients at the absolute stations and at the eccentric stands

No	Name of stand	Absolute point Eccentric stands	Gradient [mGal/m]	Error [mGal/m]
1	A-BIAL	ABS Białowieża	0.270	0.004
2	BIAL-Ex1	171 Białowieża	0.299	0.003
3	BIAL-Ex2	Białowieża – church	0.333	0.003
4	A-BG	ABS Borowa Góra	0.275	0.001
5	BG-Ex1	Borowa Góra – st.G2	0.282	0.002
6	BG-Ex2	156 Borowa Góra	0.293	0.004
7	A-BORO	ABS Borowiec	0.278	0.003
8	BORO-Ex1	0216 Borowiec	0.302	0.001
9	BORO-Ex2	Borowiec – Astrograph	0.305	0.004
10	A-GDAN	ABS Gdańsk	0.278	0.002
11	GDAN-Ex1	Gdańsk – University	0.305	0.003
12	GDAN-Ex2	11 Gdańsk	0.318	0.003
13	A-GIBY	ABS Giby	0.293	0.003
14	GIBY-Ex1	Giby – parish church	0.317	0.004
15	GIBY-Ex2	29 Sejny	0.315	0.005
16	A-KONO	ABS Konopnica	0.256	0.004
17	KONO-Ex1	Konopnica – church	0.283	0.002
18	KONO-Ex2	2406 Jasień	0.307	0.006
19	A-KOSZ	ABS Koszalin	0.296	0.002
20	KOSZ-Ex1	Koszalin –Tech. Univ.	0.314	0.006
21	KOSZ-Ex2	2 Koszalin	0.302	0.002
22	A-KSIA	ABS Książ	0.290	0.006
23	KSIA-Ex1	351 Książ	0.394	0.003
24	KSIA-Ex2	Świebodzice – church	0.307	0.005
25	A-LAMK	ABS Lamkówko	0.328	0.003
26	LAMK-Ex1	Lamkówko – cellar	0.240	0.001
27	LAMK-Ex2	Lamkówko – garden	0.328	0.004
28	A-OJCO	ABS Ojców	0.223	0.006
29	OJCO-Ex1	Ojców – concr. block	0.274	0.004
30	OJCO-Ex2	Skała – church	0.313	0.003
31	A-PIWN	ABS Piwnice	0.282	0.002

32	PIWN-Ex1	Piwnice – pavilion	0.328	0.004
33	PIWN-Ex2	Świerczynki – church	0.306	0.005
34	A-SIEN	ABS Sieniawa	0.307	0.005
35	SIEN-Ex1	Sieniawa – church	0.302	0.002
36	SIEN-Ex2	1806 Tryńcza	0.312	0.006

6. MONITORING GROUND WATER CHANGES IN THE VICINITY OF THE ABSOLUTE GRAVITY STATIONS

At absolute gravity stations especially those that are included into the geodynamic investigation programs the ground water changes should be monitored. Water level variations cause the changes of the ground density that affects measured gravity. This effect must be taken into consideration, in particular when the results are used for interpretation of the geodynamic phenomena that take place inside the Earth's crust. Therefore, at some absolute gravity stations the hydrologic tests were conducted. They indicated the need for water level monitoring at a few absolute gravity stations and further the water gauges were there installed. The heights of the upper holes of the water gauges have been determined by means of the geometric levelling with respect to the benchmarks of the vertical control network, as well as to the appropriate gravity points. The list of absolute gravity stations with their names, geographical co-ordinates and heights, as well as information on the ground water gauges and the nearest gravity network points is given in Table 3.

Table 3. Co-ordinates of the absolute stations

Name of station	φ ° ′ ta	λ ° ′ ″	h *m*	h piez. *m*	The nearest point of the gravity network
Koszalin	54 11 30	16 12 30	38,26	-	*Koszalin, No 2, 3 km*
Borowiec	52 16 37	17 04 25	79,64	80,13	*Kórnik, No 133, 5 km*
Książ	50 50 36	16 17 42	399,36	-	*Książ, No 351, 15 m*
Piwnice	53 05 44	18 33 22	82,16	84,06	*Toruń, No 70, 8 km*
Konopnica	51 21 00	18 49 20	157,77	-	*Wieluń, No 70, 14 km*
Kr-Ojców	50 13 07	19 47 43	378,00	-	*Olkusz, No 276, 16 km*
Gdańsk	54 23 46	18 34 24	20,16	-	*Gdańsk, No 11, 3 km*
Białowieża	52 42 15	23 50 59	160.00	-	*Białowieża, No 171, 40 m*
Sieniawa	50 10 16	22 36 31	177.00	-	*Leżajsk, No 301, 20 km*
Borowa Góra	52 28 32	21 02 06	106,72	108,36	*Bor. Góra, No 156, 30 m*
Lamkówko	53 53 06	20 40 15	57.00	-	*Biskupiec, No 81, 16 km*
Giby	54 02 20	23 21 45	130.00	-	*Sejny, No 29, 8 km*

7. ABSOLUTE GRAVITY AT THE ZERO-ORDER POINTS

Absolute gravity values determined with ballistic gravimeters at the zero-order network points are given in Table 4.

Table 4. Results of absolute measurements

Name of station	Date of observ.	Instrument	Gravity	Error	Observer
Borowa Góra	11/95	FG5-101	981250.586	0.001	(Falk, 1996)
	11/95	JILAg-5	.584	0.005	(Mäkinen, 1997)
	7/96	FG5-107	.587	0.004	(Stizza, 1996)
	12/97	ZZG	.602	0.004	(Ząbek, 1997)
Koszalin	11/95	FG5-101	981425.038	0.005	(Falk, 1996)
Borowiec	11/95	FG5-101	981246.147	0.002	(Falk, 1996)
	5/96	IMGC	.139	0.005	(Cerutti, 1997)
	8/98	ZZG	.164	0.004	(Ząbek, 1998)
Książ	11/95	FG5-101	981050.682	0.002	(Falk, 1996)
Gdańsk	4/86	GABL	981437.760	0.022	(Arnautov, 1986)
	7/96	FG5-107	.741	0.020	(Stizza, 1996)
	11/97	ZZG	.751	0.010	(Ząbek, 1997)
Ojców	7/96	FG5-107	981014.405	0.009	(Stizza, 1996)
Białowieża	7/96	FG5-107	981257.400	0.003	(Stizza, 1996)
Sieniawa	7/96	FG5-107	981039.470	0.005	(Stizza, 1996)
Piwnice	11/95	JILAg-5	981268.685	0.004	(Mäkinen, 1997)
	8/98	ZZG	.672	0.002	(Ząbek, 1998)
Konopnica	11/95	JILAg-5	981148.470	0.004	(Mäkinen, 1997)
	8/98	ZZG	.500	0.002	(Ząbek, 1998)
Lamkówko	5/96	IMGC	981377.614	0.005	(Cerutti,1997)
	10/97	ZZG	.635	0.002	(Ząbek, 1997)
Giby	10/97	ZZG	981391.438	0.002	(Ząbek, 1997)

Differences between the results of repeated measurements at six stations are by a factor of 3–6 larger than the accuracy of observation (5 μGal). Those differences are as follows: up to 18 μGal at Borowa Góra (without the GABLE gravimeter), 25 μGal at Borowiec, 15 μGal at Piwnice, 30 μGal at Konopnica and 21 μGal at Lamkówko. At the remaining six stations gravity was measured only ones. Although an estimated error of the determined gravity is rather small it does not express the real accuracy of the measured value of gravity. Single determination of absolute gravity at a station seems to be affected by systematic errors.

Thus the Polish (domestic) gravity standard might have been determined only after a consistent verification of the measured absolute gravity at the stations. Such verification was performed by means of relative gravity measurements made between the absolute gravity stations by means of so called the long (150–350 km) spans method.

8. VERIFICATION OF THE ABSOLUTE GRAVITY VALUES

In order to verify the gravity values obtained from absolute gravity measurements the special relative gravity measurements between the absolute gravity points were performed. Gravity differences between the pairs of the absolute gravity points have been measured using 3 or 4 LCR gravimeters. Earth tides and the atmospheric corrections were computed in the same way as in case of absolute gravity measurements (Timen L., Wenzel H.G., 1994). The differences between vertical gravity gradients at the points have also been taken into account.

The network of 25 long spans against the gravity control net is shown in Fig. 1. The mean square error of gravity differences as computed from the misclosures of the figures equals ±4 μGal. The network was adjusted as a free one tied to Borowa Góra station. Since the gravity values obtained at Borowa Góra using the JILAg-5 and both FG5 gravimeters almost did not differ, the average of those three determinations has been accepted as a constant gravity value at this point.

The mean square error of the long span measurements estimated in independent adjustment of the network equals ±5 μGal. The mean square errors of adjusted gravity differences in the long span network are of the order of ±3–4 μGal. It indicates that the accuracy of the established network is comparable with the accuracy of the absolute gravity measurements.

Twenty five values of gravity differences between absolute stations together with gravity values obtained at 12 stations form absolute observations became the basis for the verification of 21 results of absolute gravity measurements obtained in Poland with 5 absolute gravimeters tested in Sèvres. The criterion of the verification was a triple mean square error of relative gravity measurements. The analysis and comparison of all received absolute and relative gravity measurements showed that the results obtained with the JILAg-5 and both FG5 gravimeters fulfil the assumed criterion as they are very close to each other. The results obtained with the IMGC and ZZG gravimeters are the outliers in terms of that criterion. (See Table 5)

Table 5. Results of absolute and relative measurements and their comparison

Name of station	Measurement						Comparison	
	absolute				relative		difference r µGal	r/m**g**
	Date	Gravimeter	**g** mGal	m**g** µGal	**g** mGal	m**g** µGal		
1	2	3	4	5	6	7	8	9
Borowa Góra	11/95	FG5-101	981250.586	1	.586[1]	0.9[2]	0	0.0 *
	11/95	JILAg-5	.584	5			-2	2.2 *
	7/96	FG5-107	.587	4			+1	1.1 *
	12/96	ZZG	.602	4			+16	17.8
Koszalin	11/95	FG5-101	981425.038	5	.037	4.3	+1	0.2 *
Borowiec	11/95	FG5-101	981246.147	2	.150	3.9	-3	0.8 *
	5/96	IMGC	.139	5			-11	2.8 *
	8/98	ZZG	.164	4			+14	3.6
Książ	11/95	FG5-101	981050.682	2	.685	4.4	-3	0.7 *
Gdańsk	7/96	FG5-107	981437.741	20	.735	3.1	+6	1.9 *
	11/97	ZZG	.751	10			+16	5.2
Ojców	7/96	FG5-107	981014.405	9	.409	3.6	-4	1.1 *
Białowieża	7/96	FG5-107	981257.400	3	.406	3.1	-6	1.9 *
Sieniawa	7/96	FG5-107	981039.470	5	.470	4.3	0	0.0 *
Piwnice	11/95	JILAg-5	981268.685	4	.685	2.9	0	0.0 *
	8/98	ZZG	.672	2			-13	4.5
Konopnica	11/95	JILAg-5	981148.470	4	.476	3.3	-6	1.8 *
	8/98	ZZG	.500	2			+24	7.3
Lamkówko	5/96	IMGC	981377.614	5	.622	3.6	-8	2.2 *
	10/97	ZZG	.635	2			+13	3.6
Giby	10/97	ZZG	981391.438	2	.443	4.2	-5	1.2 *
Polom	9/93	FG5-107	980921.164	5	.164	8.4	0	0.0 *
Wilno	7/94	JILAg-5	981459.090	5	0.88	5.9	+2	0.3*

The stations Polom (Czechs) and Wilno (Lithuania) have been also included to the verification.

[1] – *mean value of* **g** *obtained in Borowa Góra using FG5-101, JILAg-5 and FG5-107*

[2] – *mean square error of* **g** *obtained from absolute measurements in Borowa Góra*

* – *positively verified result of absolute* **g** *(r/m**g** ≤ 3)*

Therefore, neither the result from the IMGC nor from the ZZG gravimeter was taken into account in final adjustment. Thus 12 gravity values obtained using the JILAg-5 and both FG5 No 101 and FG5 No 107 ballistic gravimeters at 10 absolute gravity stations constitute the gravity standard and the gravity level of reference in Poland. Since those gravimeters were tested several times in Sèvres and were also operated at many stations at the globe, the Polish gravity standard is adequate to the world one.

The unit of gravity has been determined on the basis of the gravity values obtained using both FG5 gravimeters at six absolute gravity stations that constitute the skeleton of the two calibration lines Koszalin – Borowiec – – Książ and Gdańsk – Borowa Góra – Ojców.

Very similar accuracy of absolute and relative gravity measurements obtained on the long spans made possible to make a joint adjustment. It provided the final gravity value at all 12 absolute gravity stations including Lamkówko and Giby. The gravity values at absolute gravity stations verified and adjusted jointly with relative gravity observations as well as the gravity at the eccentric stands are given in Table 6.

Table 6. Gravity at absolute stations and eccentric stands

No	Name of stands	Absolute points and eccentric stands	Co-ordinates		Gravity
			φ [° ' "]	λ [° ' "]	
1	A-BIAL	ABS Białowieża	52 42 13	23 51 07	981 257.403
2	BIAL – Ex1	171 Białowieża	52 42 13	23 51 07	257.155
3	BIAL – Ex2	Białowieża – church	52 42 06	23 52 33	254.759
4	A – BG	ABS Borowa Góra	52 28 33	21 02 07	981 250.586
5	BG – Ex1	Borowa Góra – G2	52 28 32	21 02 09	250.443
6	BG – Ex2	156 Borowa Góra	52 28 32	21 02 09	250.178
7	A – BORO	ABS Borowiec	52 16 37	17 04 24	981 246.148
8	BORO – Ex1	0216 Borowiec	52 16 34	17 04 29	245.275
9	BORO – Ex2	Borowiec – astrogr.	52 16 38	17 04 31	245.087
10	A - GDAN	ABS Gdańsk	54 23 47	18 34 31	981 437.737
11	GDAN – Ex1	Gdańsk – Univer.	54 23 51	18 34 33	437.258
12	GDAN – Ex2	11 Gdańsk	54 22 06	18 37 00	436.475
13	A – GIBY	ABS Giby	54 02 18	23 21 42	981 391.443
14	GIBY – Ex1	Giby - plebania	54 02 19	23 21 42	391.189
15	GIBY – Ex2	29 Sejny	54 06 35	23 20 30	401.989

16	A – KONO	ABS Konopnica	51 21 00	18 49 18	981 148.473
17	KONO – Ex1	Konopnica – church	51 21 15	18 49 45	147.245
18	KONO – Ex2	2406 Jasień	51 16 31	18 43 59	141.391
19	A – KOSZ	ABS Koszalin	54 11 12	16 11 51	981 425.038
20	KOSZ – Ex1	Koszalin – Univer.	54 11 05	16 11 49	425.131
21	KOSZ – Ex2	2 Koszalin	54 12 29	16 09 28	429.875
22	A – KSIA	ABS Książ	50 50 36	16 17 42	981 050.682
23	KSIA – Ex1	351 Książ	50 50 36	16 17 42	049.860
24	KSIA – Ex2	Świebodzice – chur.	50 51 39	16 19 21	076.533
25	A – LAMK	ABS Lamkówko	53 53 28	20 40 11	981 377.622
26	LAMK – Ex1	Lamkówko – cellar	53 53 28	20 40 14	377.983
27	LAM K– Ex2	Lamkówko – gard.	53 53 27	20 40 15	377.947
28	A – OJCO	ABS Ojców	50 13 10	19 48 12	981 014.406
29	OJCO – Ex1	Ojców – concr.bl.	50 13 10	19 48 12	014.972
30	OJCO – Ex2	Skała – church	50 13 53	19 51 15	007.818
31	A – PIWN	ABS Piwnice	53 05 42	18 33 30	981 268.685
32	PIWN – Ex1	Piwn. –pavilion	53 05 46	18 33 26	267.568
33	PIWN – Ex2	Świerczynki – chur.	53 05 55	18 31 51	267.614
34	A – SIEN	ABS Sieniawa	50 10 15	22 36 54	981 039.469
35	SIEN – Ex1	Sieniawa – church	50 10 38	22 36 33	039.399
36	SIEN – Ex2	1806 Tryńcza	50 09 09	22 34 11	038.846

The gravity control network consisting of 354 points (Fig. 1) has been adjusted with fixed 12 described above absolute gravity points and 3 absolute gravity points in Germany. Finally the network unified with regard to the gravity reference and the gravity scale as well as its construction and accuracy has been established.

ACKNOWLEDGEMENTS

This work was supported by the State Committee for Scientific Research in Poland through the grants No 9 0720 91 01 and No 9 T 12 E 016 12 as well as by the Head Office of Geodesy and Cartography, Warsaw.

The author expresses his sincere thanks to all who contributed to the measuring campaigns and to data analysis and adjustment. Particular appreciation is expressed to the colleagues from the Institute of Geodesy and Cartography, Warsaw, namely Dr. Lucjan Siporski, Dr. Andrzej Sas, Mr. Seweryn Mroczek, Mrs. Maria Cisak. Special thanks are also due to Prof. Jan Kryński for beneficial discussions and his help in preparing this paper.

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ANDRZEJ SAS-UHRYNOWSKI

ABSOLUTNE POMIARY GRAWIMETRYCZNE W POLSCE

Streszczenie

W latach 1994–1999 została założona w Polsce nowa podstawowa osnowa grawimetryczna kraju. Osnowa oparta jest na 12 punktach tzw. punktach absolutnych, na których pomiary zostały wykonane 5-ma grawimetrami balistycznymi: FG5-101, FG5-107, JILAg-5, IMGC i ZZG. Punkty absolutne zostały wybrane, zgodnie z rekomendacjami Międzynarodowej Komisji Grawimetrycznej, na najniższych kondygnacjach budynków takich jak obserwatoria, muzea, szkoły, kościoły itp. Daje to nadzieję, że punkt absolutny przetrwa w nienaruszonym stanie co najmniej kilkadziesiąt lat. Opracowanie zawiera szczegółowe opisy wszystkich punktów absolutnych. Pomiary były wykonywane przez zespoły: niemiecki, amerykański, fiński, włoski i polski. Ponieważ na kilku punktach, na których pomiary były powtarzane różnymi grawimetrami, wyniki różniły się nawet o 30 mikrogali, zaszła konieczność przeprowadzenia ich weryfikacji. W tym celu wykonano bezpośrednie pomiary nawiązujące pomiędzy punktami absolutnymi za pomocą zespołu czterech grawimetrów LaCoste & Romberg. Pomiary wykonano na 25 tzw. długich przęsłach (160–300 km). Wyniki wyznaczeń absolutnych i wyniki nawiązań względnych poddano wspólnej analizie, która umożliwiła dokonanie eliminacji grawimetrów nie spełniających założonych kryteriów pewności – IMGC i ZZG. Pozostałe grawimetry: FG5-101, FG5-107 i JILAg-5, których wskazania nie różniły się więcej niż 3 mikrogale, uznano za reprezentujące międzynarodowy standard grawimetryczny. Ich wskazania przyjęto jako wzorzec dla polskiej grawimetrycznej osnowy podstawowej. Wyniki pomiarów względnych na 685 przęsłach osnowy wyrównano w nawiązaniu do 12 wyżej wspomnianych punktów absolutnych oraz do 3 punktów na terytorium Niemiec. Uzyskano w rezultacie zbiór wartości przyspieszenia siły ciężkości dla 354 punktów osnowy, która stanowi jednorodną sieć pod względem poziomu grawimetrycznego i grawimetrycznej skali, jak również pod względem dokładności i konstrukcji.

АНДЖЕЙ САС-УХРЫНОВСКИ

АБСОЛЮТНЫЕ ГРАВИМЕТРИЧЕСКИЕ ИЗМЕРЕНИЯ В ПОЛЬШЕ

Р е з ю м е

В 1994–1999 годах была заложена в Польше новая гравиметрическая основа страны. Основа базируется на 12 пунктах, т.н. абсолютных пунктах, на которых были проведены измерения 5 баллистическими гравиметрами: FG5-101, FG5-107, JILAg-5, IMGC и ZZG. Абсолютные пункты были выбраны, согласно с рекомендациями Международной гравиметрической комиссии, на самых низких этажах зданий таких как, обсерватории, музеи, школы, костёлы и т.д. Это даёт надежду, что абсолютный пункт продержится в ненарушенном состоянии, по крайней мере, несколько десятков лет. В работе дано подробное описание всех абсолютных пунктов. Измерения выполнялись коллективами: немецким, американским, финским, итальянским и польским. Так как на нескольких пунктах, на которых измерения повторялись разными гравиметрами, результаты отличались даже на 30 микрогалов, появилась необходимость проведения их проверки. С этой целью были выполнены непосредственные привязывающие измерения между абсолютными пунктами с помощью комплекта 4 гравиметров LaCoste & Romberg. Выполнены измерения на 25 т.н. длинных пролётах (160–300 км). Результаты абсолютных определений и результаты относительных привязок были подданы общему анализу, который дал возможность исключения гравиметров, не исполняющих принятых

критериев надёжности – IMGC и ZZG. Остальные гравиметры: FG5-101, FG5-107 и JILAg-5, показания которых не отличались больше чем 3 микрогала, были признаны представляющими международный гравиметрический стандарт. Их показатели были приняты в качестве образца (эталона) для польской гравиметрической основы. Результаты относительных измерений на 685 пролётах основы были уравнены с привязкой до 12 вышеуказанных абсолютных пунктов, а также до 3 пунктов на территории Германии. В результате был получен свод величин ускорения силы тяжести на 35 пунктах основы, которая является однородной сетью как с точки зрения гравитационного уровня и гравиметрического масштаба, так и с точки зрения точности и конструкции.

Перевод: Роза Толстикова

APPENDIX 1

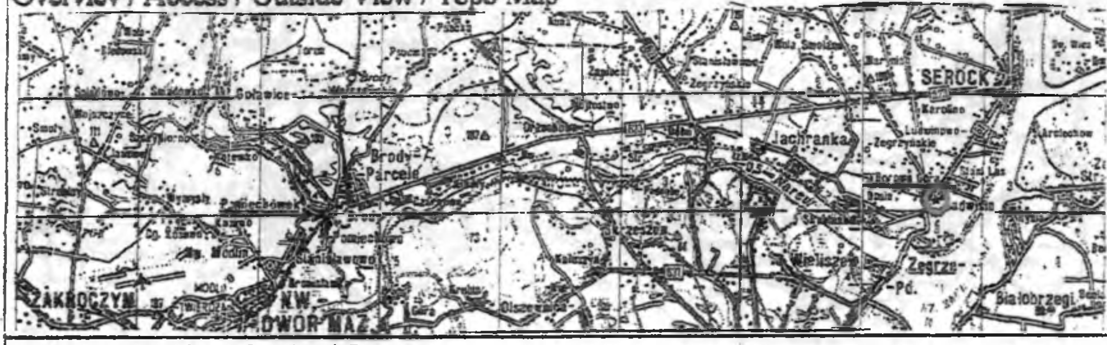
GRAPHICAL DESCRIPTIONS OF THE ABSOLUTE GRAVITY STATIONS

Absolute Gravity Basestation Network of Poland

Station Location: Borowa Góra   **Country:** Poland

$\varphi = 52°28'33''$ $\lambda = 21°02'07''$ H = 106.4 m   g = 981 250.586 mGal

Overview / Access / Outside View / Topo Map



Remarks / Station Identity / Contact

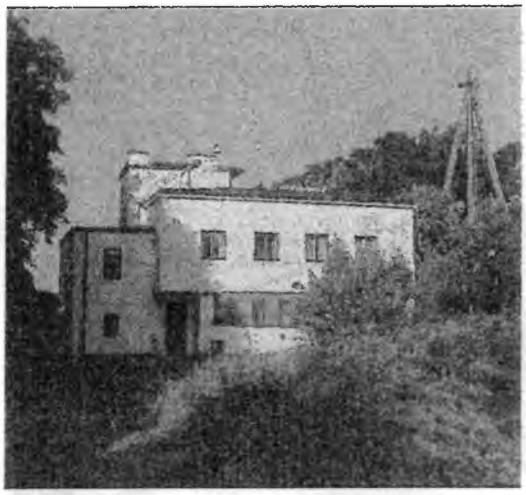
Station Address:

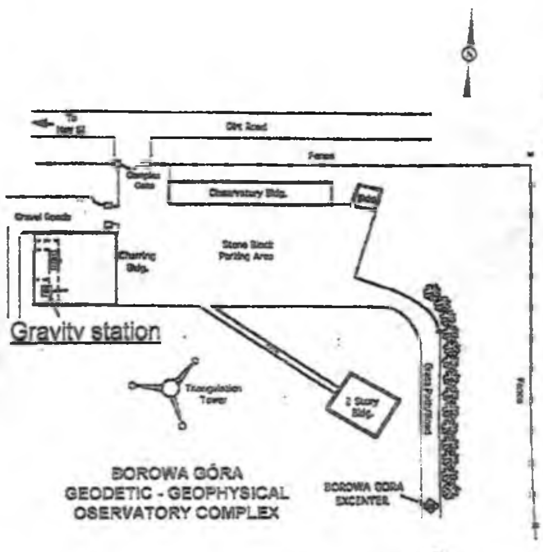
Obserwatorium Geodezyjno-Geofizyczne
Instytutu Geodezji i Kartografii
w Borowej Górze
05-140 Serock
tel. (0-22) 782-72-34

Contact Address:

Instytut Geodezji i Kartografii
ul. Jasna 2/4
00-950 Warszawa
tel/fax:(0-22) 827-03-28

Detailed Sketch (North? Station Marker?) / Photograph





Date / Autor   July 1996 D.Stizza ; Nov.1999 M.Cisak

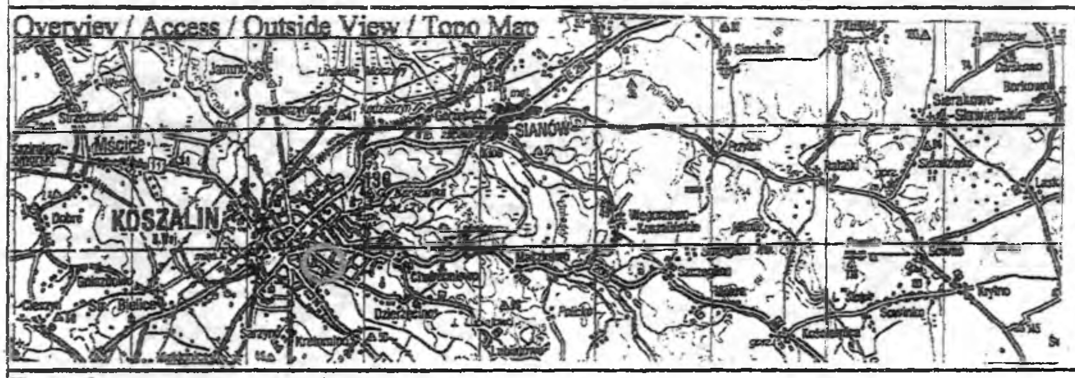
Fig.1

Absolute Gravity Basestation Network of Poland

Station Location: Koszalin **Country:** Poland

$\varphi = 54°11'12''$ $\lambda = 16°11'51''$ H = 38.3 m g = 981 425.038 mGal

Overview / Access / Outside View / Topo Map



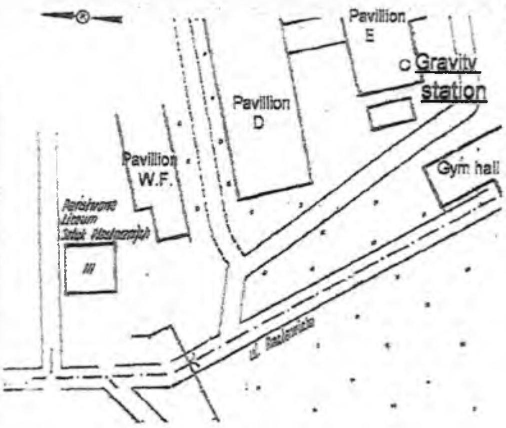
Remarks / Station Identity / Contact

Station Address:
Politechnika Koszalińska
Wydział Budownictwa i Inżynierii Środowiska
Katedra Geotechniki
ul. Raclawicka 15/17
75-620 Koszalin
tel. (094) 42-78-81 w.379

Contact Address:

Instytut Geodezji i Kartografii
ul. Jasna 2/4
00-950 Warszawa
tel/fax: (0-22) 827 03 28

Detailed Sketch (North? Station Marker?) / Photograph



Date / Author Nov. 1999/ M. Cisak

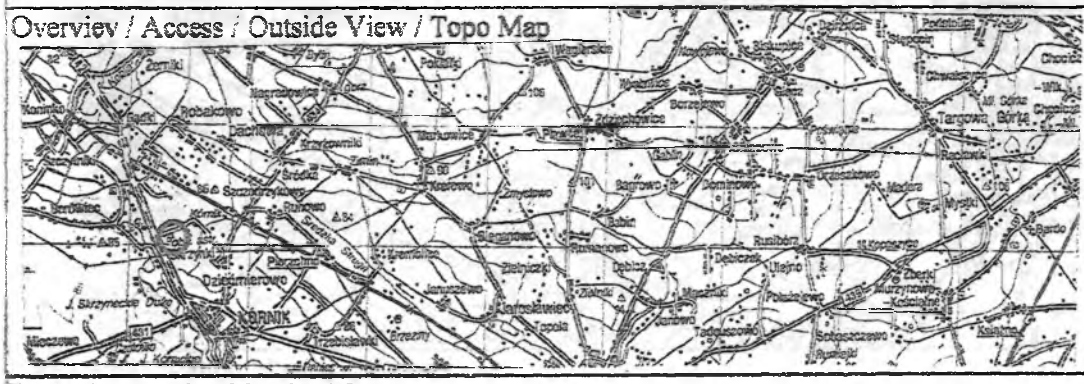
Fig.2

Absolute Gravity Basestation Network of Poland

Station Location: **Borowiec** Country: **Poland**

$\varphi = 52°16'37''$ $\lambda = 17°04'24''$ H = 79.6 m g = 981 246.148 mGal

Overview / Access / Outside View / Topo Map



Remarks / Station Identity / Contact

Station Address:

Polska Akademia Nauk
Centrum Badań Kosmicznych
Obserwatorium Astrogeodynamiczne
w Borowcu
62-035 Kórnik
tel. (0-61) 17-01-87; fax (0-61) 17-02-19

Contact Address:

Instytut Geodezji i Kartografii
ul. Jasna 2/4
00-950 Warszawa
tel/fax: (0-22) 827-03-28

Detailed Sketch (North? Station Marker?) / Photograph

Date / Author Nov. 1999 / M.Cisak

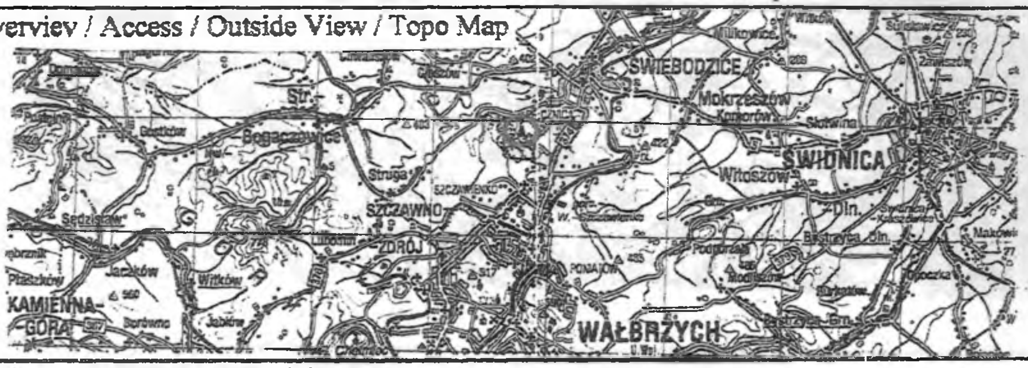
Fig.3

Absolute Gravity Basestation Network of Poland

Station Location: **Książ** Country: **Poland**

$\varphi = 50°50'36''$ $\lambda = 16°17'42''$ H = 399.4m g = 981 050.682 mGal

Overview / Access / Outside View / Topo Map



Remarks / Station Identity / Contact

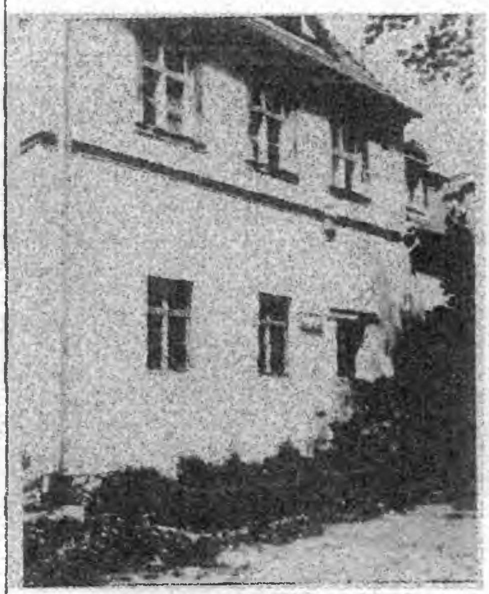
Station Address:

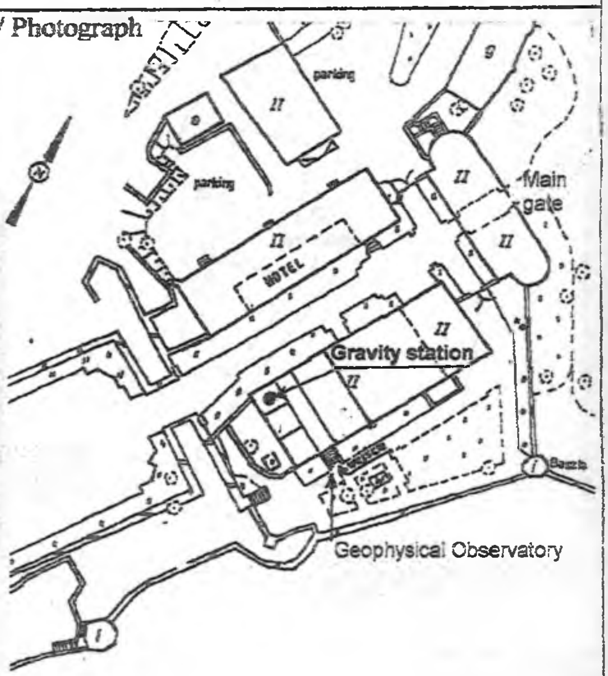
Dolnośląskie Obserwatorium Geofizyczne
Instytutu Geofizyki PAN
ul. Piastów Śląskich 1
58-306 Wałbrzych
tel (0-74) 40-07-77 fax (0-74) 43-26-79

Contact Address:

Instytut Geodezji i Kartografii
ul. Jasna 2/4
00-950 Warszawa
tel/fax: (0-22) 827-03-28

Detailed Sketch (North? Station Marker?) / Photograph





Date / Author Nov. 1999 / M.Cisak

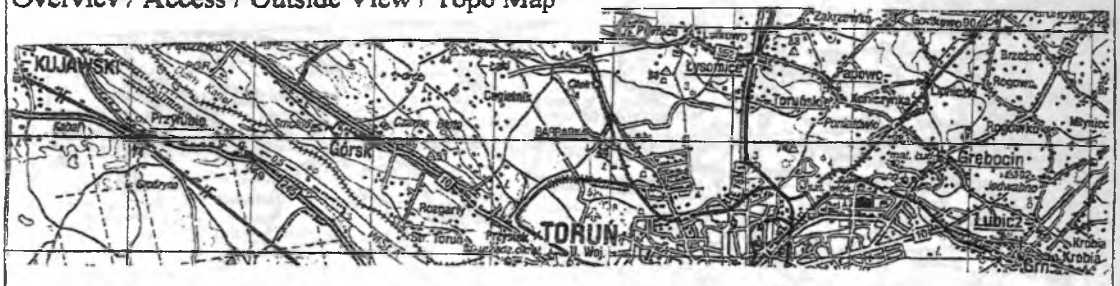
Fig.4

Absolute Gravity Basestation Network of Poland

Station Location: **Piwnice** Country: **Poland**

$\varphi = 53°05'42''$ $\lambda = 18°33'30''$ H = 82.2 m g = 981 268.685 mGal

Overview / Access / Outside View / Topo Map



Remarks / Station Identity / Contact

Station Address:

Obserwatorium Astronomiczne
Uniwersytetu Mikołaja Kopernika
Piwnice k. Torunia
87-147 Łysomice
tel. (0-56) 611-30-05

Contact Address:

Instytut Geodezji i Kartografii
ul. Jasna 2/4
00-950 Warszawa
tel/fax: (0-22) 827-03-28

Detailed Sketch (North? Station Marker?) / Photograph

Date / Author Nov. 1999 / M. Cisak

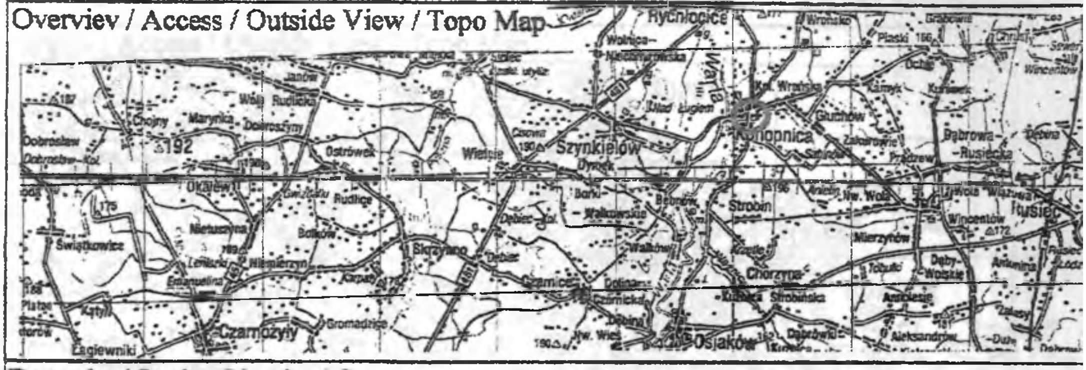
Fig.5

Absolute Gravity Basestation Network of Poland

Station Location: **Konopnica** Country: **Poland**

$\varphi = 51°21'00''$ $\lambda = 18°49'18''$ H = 157.8 m g = 981 148.473 mGal

Overview / Access / Outside View / Topo Map



Remarks / Station Identity / Contact

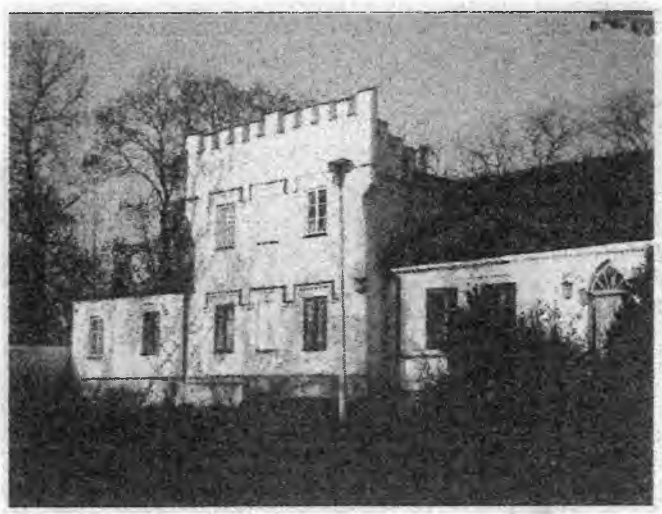
Station Address:

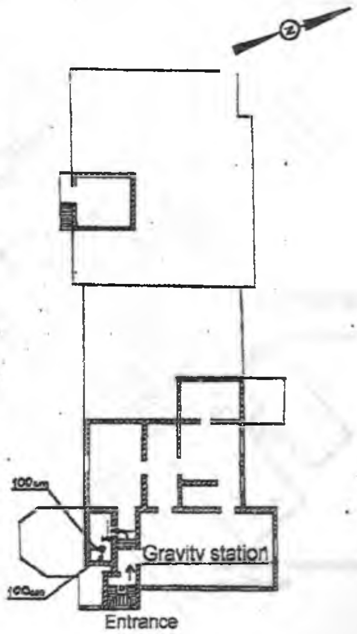
Dom Pracy Twórczej Politechniki Łódzkiej
ul. Parkowa 5
98-313 Konopnica
tel. (0-43) 842-44-22

Contact Address:

Instytut Geodezji i Kartografii
ul. Jasna 2/4
00-950 Warszawa
tel/fax: (0-22) 827-03-28

Detailed Sketch (North? Station Marker?) / Photograph





Date / Author Nov. 1999 /M. Cisak

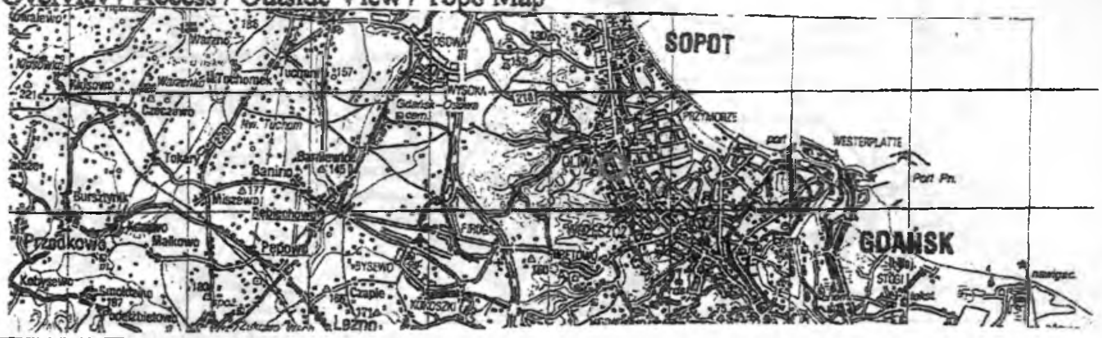
Fig.6

Absolute Gravity Basestation Network of Poland

Station Location: Gdańsk **Country:** Poland

$\varphi = 54°23'47''$ $\lambda = 18°34'31''$ H = 20.2 m g = 981 437.737 mGal

Overview / Access / Outside View / Topo Map



Remarks / Station Identity / Contact

Station Address

Instytut Fizyki Uniwersytetu Gdańskiego
ul. Wita Stwosza
80-312 Gdańsk-Wrzeszcz
tel. (0-58) 552-92-62
(0-58) 552-92-89

Contact Address:

Instytut Geodezji i Kartografii
ul. Jasna 2/4
00-950 Warszawa
tel/fax: (0-22) 627-03-28

Detailed Sketch (North? Station Marker?) / Photograph

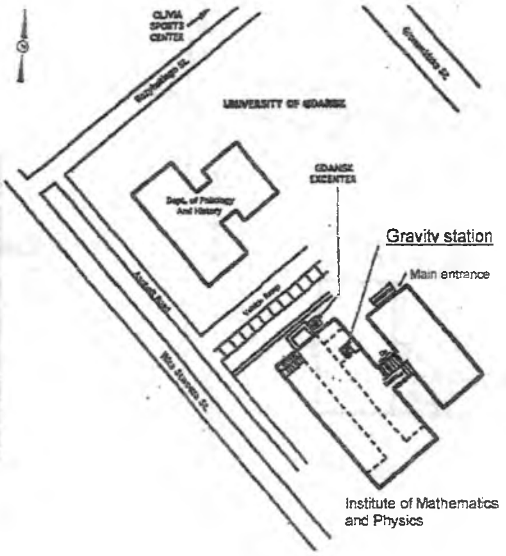


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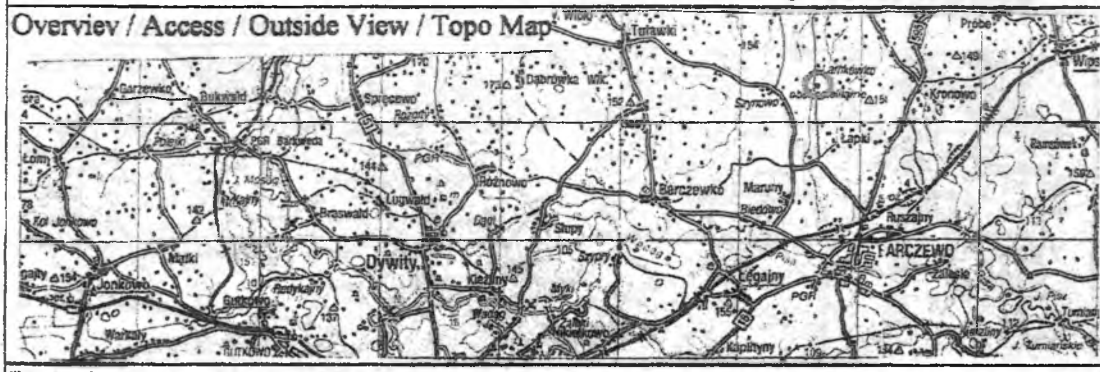
Fig.7

Absolute Gravity Basestation Network of Poland

Station Location: **Lamkówko** Country: **Poland**

$\varphi = 53°53'28''$ $\lambda = 20°40'11''$ H = 157 m g = 981 377.622 mGal

Overviev / Access / Outside View / Topo Map



Remarks / Station Identity / Contact

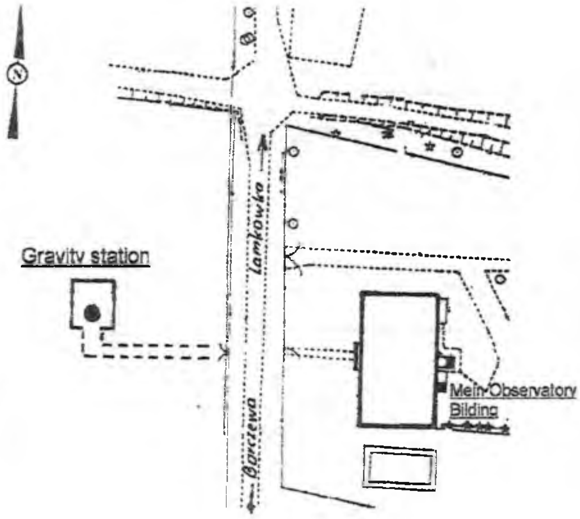
Station Address:

Obserwatorium Satelitarne
Uniwersytetu Warminsko-Mazurskiego
11-012 Lamkowo
Lamkówko13
tel. (0-89) 514-16-84.

Contact Address:

Instytut Geodezji i Kartografii
ul. Jasna 2/4
00-950 Warszawa
tel/fax: (0-22) 827-03-28

Detailed Sketch (North? Station Marker?) / Photograph



Date / Author Nov. 1999 / Maria Cisak

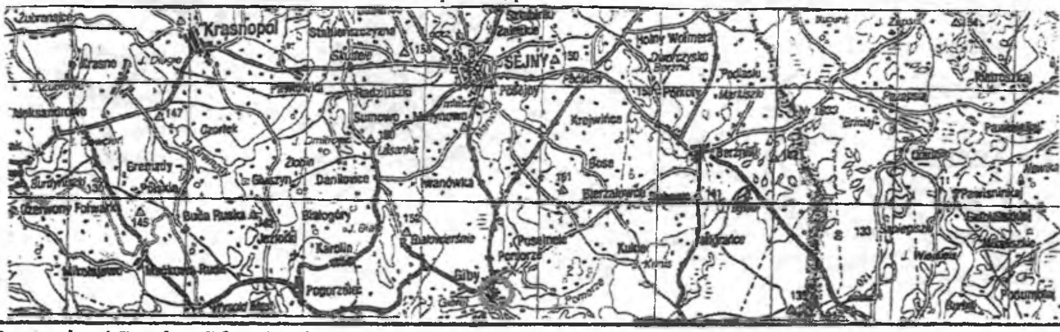
Fig.8

Absolute Gravity Basestation Network of Poland

Station Location: Giby **Country:** Poland

$\varphi = 54°02'18''$ $\lambda = 23°21'42''$ H = 140 m g = 981 391.443 mGal

Overviev / Access / Outside View / Topo Map



Remarks / Station Identity / Contact

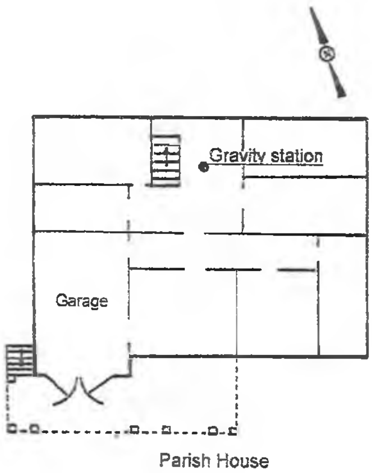
Station Address:

Parafia Rzymsko-Katolicka
w Gibach
16-506 Giby
tel. (0-87) 16-50-74

Contact Address:

Instytut Geodezji i Kartografii
ul. Jasna 2/4
00-950 Warszawa
tel/fax: (0-22) 827-03-28

Detailed Sketch (North? Station Marker?) / Photograph



Date / Author Nov. 1999 / M. Cisak

Fig.9

Absolute Gravity Basestation Network of Poland

Station Location: Białowieża Country: Poland

φ = 52°42'13" λ = 23°51'07" H = 164 m g = 981 257.403 mGal

Overview / Access / Outside View / Topo Map

Remarks / Station Identity / Contact

Station Address:

Polska Akademia Nauk
Zakład Badania Ssaków
17-206 Białowieża
tel. (0-85) 681-22-78
(0-85) 681-22-89

Contact Address:

Instytut Geodezji i Kartografii
ul. Jasna 2/4
00-950 Warszawa
tel/fax: (0-22) 827-03-28

Detailed Sketch (North? Station Marker?) / Photograph

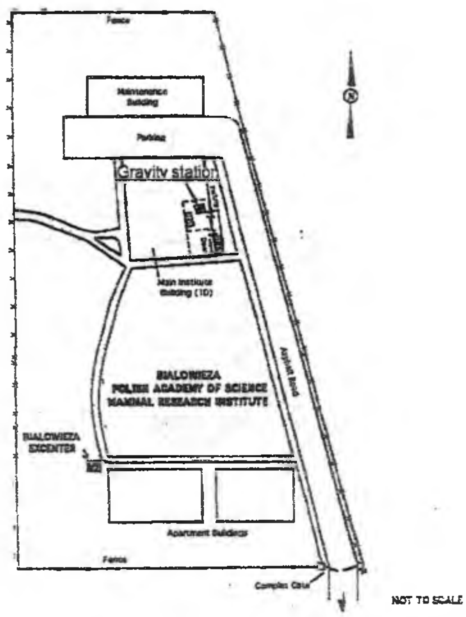


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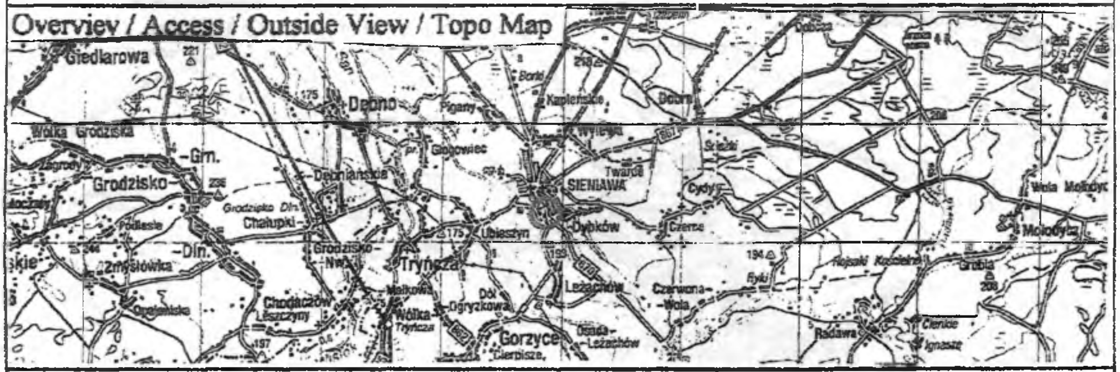
Fig.10

Absolute Gravity Basestation Network of Poland

Station Location: Sieniawa **Country:** Poland

$\varphi = 50°10'15''$ $\lambda = 22°36'54''$ H = 177 m g = 981 039.469 mGal

Overview / Access / Outside View / Topo Map



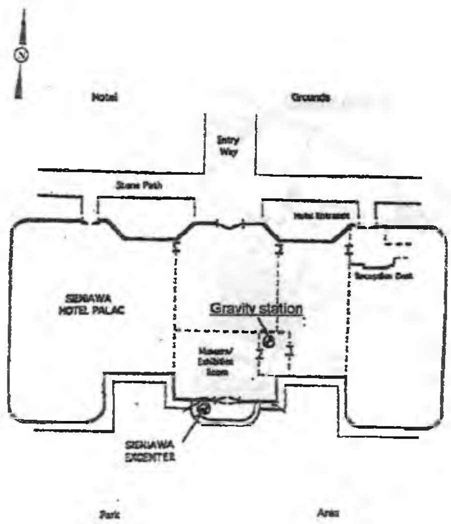
Remarks / Station Identity / Contact

Station Address
Zespół Pałacowo-Parkowy
ul. Kościuszki 32
37-530 Sieniawa
tel/fax (016) 621-61-01

Contact Address:

Instytut Geodezji i Kartografii
ul. Jasna 2/4
00-950 Warszawa
tel/fax: (0-22) 827-03-28

Detailed Sketch (North? Station Marker?) / Photograph



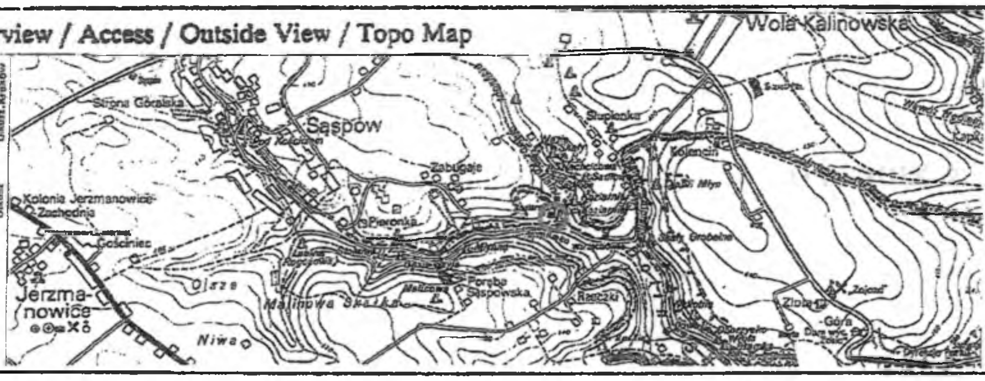
Date / Author July, 1996 / D.Stizza ; Nov. 1999 / M.Cisak

Fig.11

Absolute Gravity Basestation Network of Poland

Station Location: Ojców	**Country:** Poland
$\varphi = 50°13'10''$ $\lambda = 19°48'12''$	H = 378 m g = 981 014.406 mGal

Overview / Access / Outside View / Topo Map



Remarks / Station Identity / Contact

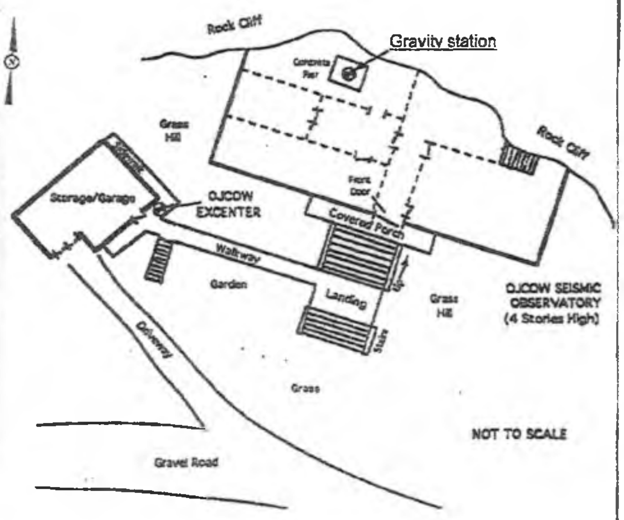
Station Address:

Obserwatorium Sejsmologiczne
Instytutu Geofizyki PAN
32-047 Ojców
tel/fax: (0-12) 23-95-84

Contact Address:

Instytut Geodezji i Kartografii
ul. Jasna2/4
00-950 Warszawa
tel/fax:(0-22) 827-03-28

Detailed Sketch (North? Station Marker?) / Photograph



Date / Author July 1996 / D. Stizza · Nov.1999 / M. Cisak

Fig.12

APPENDIX 2

CONNECTION OF THE JÓZEFOSŁAW AND KROKOWA UNIGRACE ABSOLUTE GRAVITY STATIONS WITH THE ZERO-ORDER NETWORK

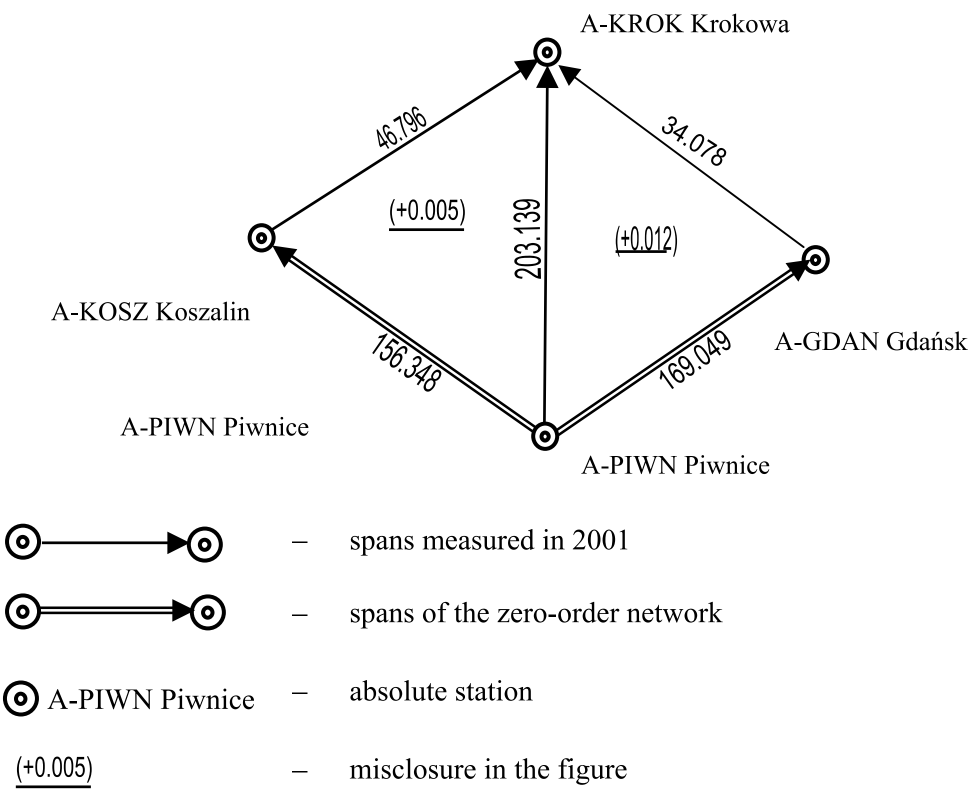
Connection of the Józefosław and Krokowa UNIGRACE absolute gravity stations with the zero-order network

In 2001, the Józefosław and Krokowa absolute gravity stations of the UNIGRACE project were connected with the zero-order network. Both stations were connected with three absolute gravity stations. The Józefosław station was connected with Borowa Góra, Borowiec and Piwnice. The Krokowa station was connected with Piwnice, Koszalin and Gdańsk. The measurements of the gravity differences between stations mentioned above were made 3 times by means of the long span method, using four LCR gravimeters. Back and fore measurements of each span were performed for three days with three of four gravimeters. The scales of gravimeters were controlled on the central calibration line. The Earth tide correction was computed in the same way as in case of previous measurements. On each stand the atmospheric pressure was also measured and the appropriate correction was implemented to the results. The results were reduced to the upper plane of the pillar by implementing the gradient correction. The final result of gravity difference on the long span corresponds to the average from all measurements on the span.

Misclosures in the figures, formed from two connecting long spans and one long span between the stations of the zero-order network, are shown in drawings. Tables give the final results of connection. The comparison between the results obtained from connection and the ones obtained from absolute measurements at Józefosław and Krokowa is not discussed since the results of absolute measurements, performed within the UNIGRACE project, are not available yet.

Connecting measurements for Krokowa Station in 2001, using LaCoste & Romberg gravimeters

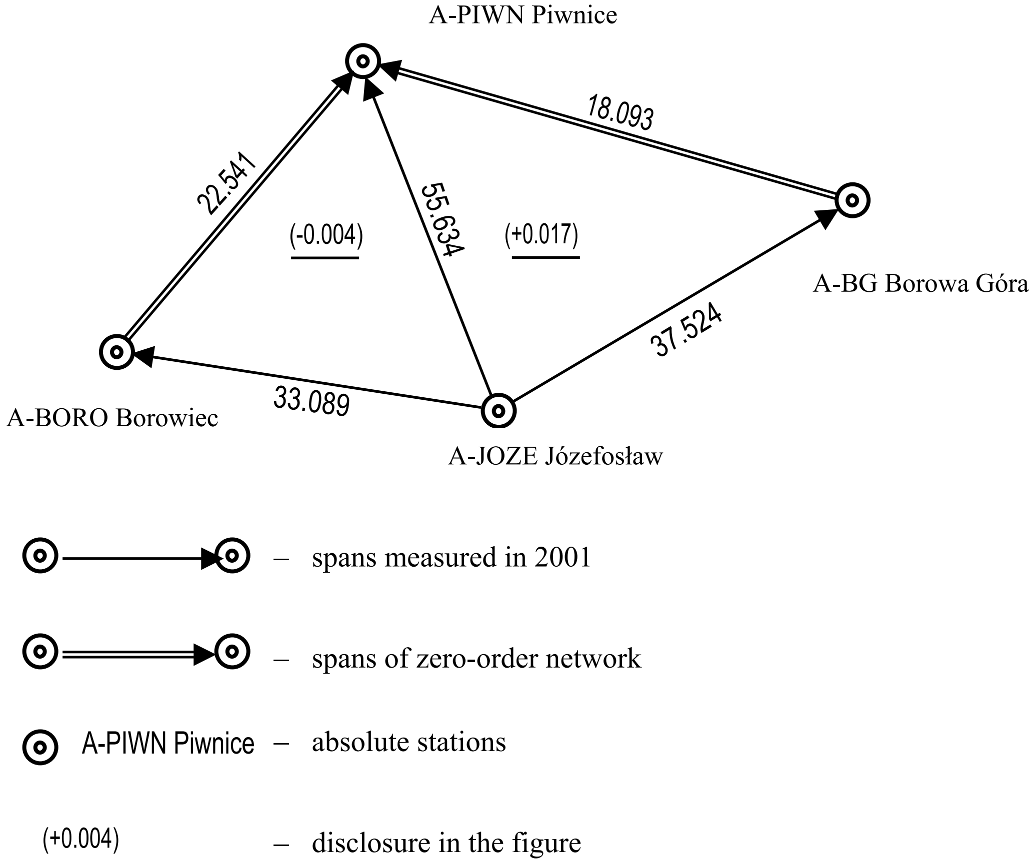
No.	Name of the span	from – to	Difference	Error
1	KRO - GDA	A-KROK Krokowa – A-GDAN Gdańsk	-34.078	±0.005
2	KRO - KOS	A-KROK Krokowa – A-KOSZ Koszalin	-46.796	±0.004
3	KRO - PIW	A-KROK Krokowa – A-PIWN Piwnice	-203.139	±0.004



The adjusted value of gravity at Krokowa, obtained from relative connecting measurements: **981 471.822**

Connecting measurements for Józefosław Station in 2001,
Using LaCoste & Romberg gravimeters

No.	Name of The span	from – to	Difference	Error
1	JOZ - BG	A-JOZE Józefosław – A-BG Borowa G.	37.524	±0.005
2	JOZ - PIW	A-JOZE Józefosław – A-PIWN Piwnice	55.634	±0.010
3	JOZ - BOR	A-JOZE Józefosław – A-BORO Borowiec	33.089	±0.009



The adjusted value of gravity at Józefosław, obtained from relative connecting measurements: **981 213.058**