

National Gravity System for Bulgaria¹

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Abstract. The necessity of establishment of National Gravity System have been discussed. It presents itself a further realisation of projects UNIGRACE, CERGOP and EUREF (EUVN, EVRS) on the territory of Bulgaria. It is a base of solving actual and future Bulgarian national objectives of Geodesy and Geophysics as like as the development of an unified gravity system and network, introducing the Bulgarian Geodetic System BGS 2000, determination of sea level changes, determination of the local geoid for Bulgaria and many others. The system is also related to the European integration of Bulgaria and determination of the European geoid.

1 General

The problem for establishment of National Gravity System for Bulgaria is a question of present interest by reason of the continuous development of science, integration in European and world scale and the necessity to solve many national, regional and global aspects of geodesy, and the other Earth sciences, determination of national and European

geoid, and many other scientific and applied aspects.

Absolute gravity measurements and determinations were carried out in the country (in 1942 one point in Sofia, in 1981, 1983, 1986 in Sofia and in 1981 in Varna, connected to the Potsdam station in Germany) and a National Gravity Network of 100 points in two orders was established. A calibration gravity line between Vidin and Melnik was established, too [3]. However these results have been obtained at different level of science and technics development.

By this reason it is necessary to be given proof of new system for the country and proposal for such a system which has to be based on the results of the now-days achievements and possibilities in this field of science. It should be based on the contemporary analysis of the established similar systems in Europe, on the tendency to unify and establish unified European gravity and height system, and European geoid.

They are consequences of active international collaboration within the framework of EU, European Reference System, International Association of Geodesy and the collaboration between Balkan countries as well [2], [4], [5]. The

¹ The paper is based on the results obtained from the accomplished works except on the here mentioned projects and also on the project under development with the same name within the framework of National Council "Scientific Investigations" (NC"SI") of the Ministry of Education and Science (MES) of the Republic of Bulgaria.

system should also meet the complex requirements and to become an element in the establishment of unified national geodetic system and network as an element of the European and world system, respectively. Along with that preconditions for unification and establishment of unified national GPS (Global Positioning System), levelling and gravity system, and national standardization in this aspect have to be found.

The expected results could be summarized as follows:

- Establishment of relevant national gravity system along with the project for its realisation
- Further unification within the framework of European gravity system and geoid
- Suggestion for an advisable way to maintain the system.

The works having in mind to be accomplished are related to:

- Establishment validity of unified gravity system for Bulgaria, project for National Gravity Network,
- Integration the renewed gravity network with the national levelling and forthcoming GPS network of the country,
- Determination of the absolute gravity standard for Bulgaria with the highest precision ($\pm 20 - 30 \text{ nms}^{-2}$),
- Availability of preconditions for common definition of unified height system and determination of the geoid for Bulgaria,
- Availability of unified European reference system for geophysical studies at the exploitation of natural resources.

The present paper and the establishing system respectively are based on the works accomplished within the framework of the international project UNIGRACE (Unification of the Gravity Systems of the Countries from Central and Eastern Europe), on the projects EUREF (European Reference Frame), EUVN (European Vertical Reference Network), EVRS and projects CERGOP (Central European Regional Geodynamics Project) -1 and 2 [1,4,5,6,8]. The reasons for extension and development of the investigations and tendency of further activities in this field are outlined.

2 Implementation of the UNIGRACE, EUREF, EUVN, EVRS and CERGOP projects on the territory of Bulgaria

2.1 Implementation of the UNIGRACE project

Three absolute gravity stations – Sofia, Plana (40 km south-east of the Sofia station) and Varna at the Black Sea coast, near-by the Varna tide gauge were established in 1998, according to the project UNIGRACE, jointly with the Federal Office of Metrology and Surveying (BEV), Austria (Fig. 1) [5]. The stations in Sofia and Varna are identical with stations where the absolute measurements have been carried out, mentioned in section 1.

An absolute gravimeter JILA 6 (FF), drop mode of BEV was used for measurements in 1998.



Fig. 1: Map of gravity stations

A calibration line between stations Sofia-Plana was established with two intermediate points (Fig. 2). Two more points were included in the site of national geodetic observatory – one of them located on the antenna pillar of the EUREF Permanent station near Sofia and the other one – on the foundation of the telescope room.

Relative measurements have been also carried out at the absolute station in Varna. The Black Sea gauges in Varna, Hirakli and Burgas as well as the GPS observation pillars near the gauges, which are stations of the EUVN levelling network of EUREF were connected to this station (Fig. 3). The measurements were carried out with two relative gravimeters LCR-D51, ownership of BEV and LCR-1095 – ownership of the University of Architecture, Civil Engineering and Geodesy, Sofia.

The absolute stations Sofia and Varna are also stations of the National Gravity Network.

Second time measurements were carried out at the absolute stations Sofia and Plana with absolute gravimeter ZZG, ballistic method and in the respective micronets with the relative gravimeter

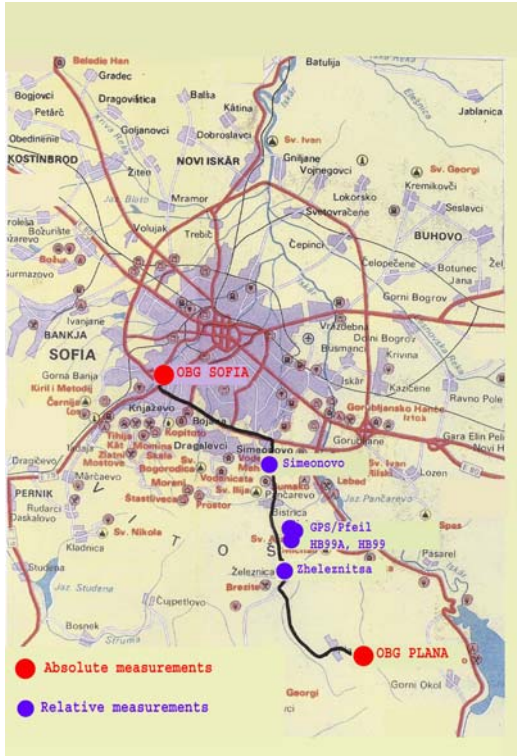


Fig. 2: Calibration Line Sofia-Plana



Fig. 3: Connection of EUVN GPS stations, tide gauges and levelling benchmarks

LCR – G986 of the Geodetic and Astronomic Institute of the Warsaw Technology University, Poland in 2001.

For the study of influence of the underground water changes in the region around the Sofia station it was also built a system and respective geodetic, and hydrologic measurements, analyses and generalisations were carried out.

The achieved accuracy in the absolute gravity determination after final data processing of two campaigns is shown in table 1.

Table 1: Results of final data processing

Code	Independent measurements	g 10 ⁻⁸ [m.s ⁻²]	σ 10 ⁻⁸ [m.s ⁻²]
OBG Plana	10	980 074 440.0	3.0
		980 074 339.5	1.0
OBG Sofia	7	980 240 584.4	5.6
OBG Varna	5	980 470 768.3	6.0

These values are representative for Bulgaria and they will be basis for further uses and unification for the territory of the country, and will serve as standard.

The accomplished works and the obtained generalised results from the realization of the UNIGRACE project in Bulgaria can be summarized in the following:

- establishment of three absolute stations
- Data processing and estimation of the results of the absolute gravity measurements obtained from two campaigns by common reference of two instruments;
- establishment a calibration line and two micronets;
- connection of the Bulgarian UNIGRACE stations with the national gravity network, with the EUREF permanent station and EUVN GPS stations, with tide gauges and other points;
- determination of normal heights and geopotential numbers of the gravity points;
- building up a hydrogeologic system around the absolute gravity station SOFIA.

More detailed information and specific results for Bulgaria and the UNIGRACE project as a whole are presented in [5].

2.2 Implementation of the EUREF, EUVN, EVRS and CERGOP Projects

EUREF has been established by methods of very long baseline interferometry, lunar laser location and satellite laser location, and mainly by GPS. As a result a network of geodetic determined stations by GPS and network of permanent GPS stations has been established. Bulgaria participates with 15 stations (Fig. 4). Two GPS measurement campaigns were carried out in 1992 and 1993. The results of data processing were accepted at the Ankara Symposium in 1996 and Bulgaria was officially

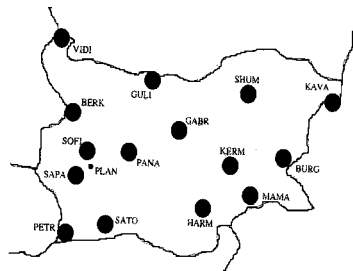


Fig. 4: EUREF – BULREF stations

included in EUREF with the seventh of the fifteenth stations [6]. Since May 1997 a permanent GPS station is operated as a part of the EUREF permanent network. It is already an element and operates in the world IGS network of permanent stations. EUREF is a base for establishment of the national GPS network and it is an element of the introducing of Bulgarian Geodetic System 2000.

Bulgaria participates in the subproject of EUREF – European Vertical Network (EUVN). It is based on the specially established GPS network and on the many different measurements with the aim to achieve the following scientific-technical results:

- establishment of unified height system of the continent in short time
- connection with the European tide gauges to monitor the absolute sea level variations
- establishment of control stations for determination of the European geoid
- preparation for establishment of the European height geodynamic network.

EUVN includes 79 EUREF points, 53 points of the national levelling networks and 63 tide gauges. Three stations involved the territory of the country in EUVN. Two of them BG01 and BG04 are built as special pillars for GPS measurements and they are located at the Black Sea coast near the tide gauges in Burgas and Varna, respectively (Fig. 1).

Station BG03 is the pillar where the antenna of the permanent GPS station Sofia is installed. The gravity values of the stations were measured during the time of UNIGRACE project on the COPERNICUS Program. Their normal heights were also determined and the levelling connection with the control benchmarks at the tide gauges were realised, too. The monthly values of the mean sea level for the period 1977-2000 were determined as well. It was submitted to the Data Processing Center in France. The tide gauge values for the period 1928-1996 are available in PSMSL in England [7].

Realisation of EVRS on the territory of Bulgaria is determined by the successful involving of the national levelling network along with a supplementary information in the database of the United European Levelling Network (UENL). For this purpose it was accomplished a preparation of the levelling Network 1st-order data. Differences between geopotential numbers of levelling benchmarks, geographic latitudes and longitudes, and normal heights of the benchmarks were determined in Baltic system. A special preparation for a connection with the levelling networks of the neighboring countries and mainly with Romania that is very essential for the connection with UENL is going.

In the works accomplished within the framework of the IAG Section V“Geodynamics” are included “Geodetic and Geodynamic Programs of the Central European Initiative (CEI)” and Central European Regional Geodynamics Project CERGOP – 2. In the latter is also created a working group for geotectonic analysis of the region of Central Europe [4]. Special subgroup is devoted to the Geodynamics of Balkan Peninsula. According to the project for complex investigations, a specially established GPS network CEGRN is observed every two years. On the base of EUREF that includes three stations of CEGRN, Bulgaria actively participates in this program and projects. Further GPS measurements are foreseen on the base of EUREF stations of the Central European region and the region of the Balkan Peninsula as well.

Here discussed measurements and investigations are serious and absolutely necessary precondition for establishment of a new precise National Gravity System corresponding to the standards of the European System

3 Unified Gravity System and Network

Forthcoming activities on the establishment of National Gravity System are aimed at two aspects:

- Unification of the reference gravity system
- Preparation and realisation of the control gravity network of the country.

Unification of the reference gravity system includes:

- Method for homogeneous national gravity information, its transformation to the new Gravity Reference System (GRS) and its standardization by the proposed system
- Model for periodic and permanent part of the tide effect, for transition to different tide system and for the atmospheric influence
- Corrections to the gravity because of the effects causing deformation in consequence of the polar motion for reduction of precise gravity measurements to the actual epoch of Geodetic reference system (GRS).
- Development of a new gravity anomaly system at the renewing and unifying of the free-air reduction model and Bouguer anomalies as well as their transformation to the new GRS.
- Correction of the gravity because of the transition from the present system to the new gravity datum and assessment of the normal height changes and normal corrections at this transition

Preparation and realisation of the control gravity network of the country includes:

- New model of the anomaly calculations for the free-air reductions on the base of geocentric spatial coordinates and normal point heights of the control gravity network and achievement of homogeneous gravity anomaly system.
- Development of methods for establishment of the national gravity datum on the base of the absolute gravity measurements on the UNIGRACE project.
- Technology of correction, processing and transformation of the control gravity network data by introducing of new standards.
- Assessment of the hydrological effects on the gravity datum definition and the control gravity network scale.

These unification elements, models, methods, technology and assessments are determined and they are in the process of use.

4 Specific applications

Next steps of development, regulation and introducing of the system as an element of solving the common problems of the country related to the European integration along with these ones given in section 3 are as follows.

A geodetic system for the territory of Bulgaria named Bulgarian Geodetic System 2000 (BGS2000) was defined by Act of the Council of Ministers of Republic of Bulgaria (140/15.06.2001). It includes :

- Fundamental geodetic parameters defined in geodetic reference system 1980 (GRS80);
- Geodetic coordinate system ETRF-89 realised by the European reference frame EUREF;
- Vertical system realised by the National levelling benchmarks determined with respect to the European Vertical Reference Network (EUVN) supplemented with gravity data in an unified gravity system;
- System of plane map coordinates based on the ETRF-89 and the conformal conic projection (Lambert projection) with two standard parallels and one central meridian which is used for all civil applications;
- International system for gridding and nomenclature of the map sheets up to scale 1: 2000 including.

A project "National Gravity System" to solve the main problems of the national gravity system is being developed within the framework of National Council "Scientific Investigations" (NC"SI") of the Ministry of Education and Science (MES) of the Republic of Bulgaria.

5 Conclusion and Suggestions

Presented problems, realisation of the mentioned projects and respectively drawn generalisations related to the basic geodetic works including the national gravity system as well as the next specific steps and determinations are preconditions for the full realisation of this system within the framework of further unification and complex European integration.

In this sense it is suggested the works to be continued according to the proposals and resolutions of the EUREF and the gravity and geoid commissions of IAG, and the project of the SC"SI" of MES.

6 Final Remark

The National Gravity System of Bulgaria is a necessary element for the solution of the complex national geodetic and other problems of the country and European integration as the works on its realisation have to be actively continued.

References

- Altiner, J., P. Gabenski, K. Habrich, G. Milev, M. Minchev, H. Seeger, K. Vassileva. EUREF Bulgaria GPS Campaigns Final Results. EUREF- Symposium, Ankara, Turkey, 22-25 May 1996, DGK. Muenchen. AGA. 1996, Heft 57, 86-97
- Ihde, J., J. Adam, C. Bruynix, A. Kenyeres, J. Simek. Development of an European Integrated Permanent Network (EPN-I). EUREF Symposium in Ponta Delgada, Azores Islands, Portugal, 5-8 June 2002. 14
- Mihailov, E. Analysis of the calibration gravity network of the Republic of Bulgaria. *Annuaire de L'universite d'architecture, de genie civil et de geodesie - Sofia*. 1998, Vol. XXXIX, fasc. III, 233-240 (in Bulg.)
- G. Milev, J. Sledzinski, K. Vassileva. Geodynamic investigations of the Balkan Region within the framework of CEI- CERGOP2. 3rd Balkan geophysical congress and exhibition. 24-28 June 2002. Sofia. Bulgaria. Book of Abstracts. 347
- Milev, G., L. Stoyanov, D. Ruess, A. Pachuta, K. Vassileva. Bulgarian UNIGRACE Report. *Mitteilungen des Bundesamtes fuer Kartographie und Geodaesie*. Verlag des BKG, Frankfurt am Main. 2002. 18. (in press)
- Milev, G., L. Stoyanov, M. Minchev, T. Beljashki, K. Vassileva, E. Peneva, E. Mihailov, E. Rangelova. European reference systems and Bulgarian participation in their realisation. In: Reports of jubilee scientific session "50 years Central laboratory of Geodesy", November 24, 1998. Sofia, BAS, 1998, 15-24 (in Bulg.)
- Milev, G., G. Valev, M. Minchev, K. Vassileva, T. Tashkov, K. Gegov, T. Beljashki. National report of Bulgaria. EUREF symposium in Punta Delgada, Azores islands, Portugal, June 5 – 8, 2002. *Mitteilungen des Bundesamtes fuer Kartographie und Geodäsie*. 2002, Band 24. EUREF Publikation No 11
- Reinhart E., B. Richter, H. Wilmes, E. Erker, D. Ruess, J. Kakkuri, J. Mäkinen, I. Marson, J. Sledzinski. UNIGRACE – A project for the unification of gravity systems in Central Europe. Presented at the Second Continental Workshop of the IAG Subcommission for the geoid in Europe "Progress in the construction and Use of Precise Geoid Models for the European Continent", Budapest, March 10-14, 1998.