Problem of development high-precision local model of quasigeoid

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Abstract. The description and the topicality of the geodetic heights transformation to the quasigeoid reference surface were shown. The problem-solving techniques, the level of the topic scientific development and perspectives for further research of the local Height Reference Surface modeling are under consideration.

Introduction
At the present day, the main and the most available method of high-precision determination of heights (elevations) in their physical meaning is geometric leveling. This method assumes direct observation, as elevations are determined relatively to the surface normal to vertical. With the active implement of satellite co-ordinate technologies the determination of heights based on observations of global navigation satellite systems becomes an alternative to the geometric leveling. The main disadvantages of the method are indirect determination of values and relative altitudes referred to reference ellipsoid, which called geodetic heights. In the Russian Federation, the quasi-geoid surface is assumed as the reference surface and heights are referred to Baltic normal height system. This fact excludes the possibility of implementation the satellite determination technology without strict relations to the reference surfaces. At the planetary scale, the connection of the systems is realized through the geoid models, which consist of a set of elevations geoid heights above the ellipsoid on a regular grid.

Therefore the presence of quasi-geoid model assumes knowing the differences between the geodetic and normal heights in any point of the planet or, at least, in nodes equiangular grid covering the Earth. At the present day, a maximum error of the quasi-geoid surface determination is in the order of 1m, which is obviously insufficient for the high-precision leveling. It was found that in order to calculate the heights of global quasi-geoid with sufficient accuracy it is required to determine gravity anomalies at a level unobtainable for advanced gravimetric equipment [3, 6]. Therefore, the development of more accurate local quasi-geoid models allowing the satellite co-ordinate determination technologies fully implemented in a limited area remains urgent. However, current regulations and standards is out of date and leaves out capabilities of modern measuring and computing equipment. That is why it does not imply the accomplishment of similar works, which seriously complicates practical implementation of the local models.

Within the problem under consideration the reduction of geodetic heights to the surface of quasi-geoid results in the constructing of more accurate model which makes possible using of satellite data for high-precision leveling.

A brief review of modern geopotential models
Until recently, the most accurate global model of Earth’s gravity field was EGM96. The model is based on the set of expansion coefficients of Earth’s gravity field according to spherical harmonics to 360 degrees and includes anomalies over a regular 30-minutes grid. A serious step increasing the accuracy of the model was GRACE mission satellite launch in 2002 year aimed at the Earth’s gravity field and time variations research. The GRACE satellites, which operation was planned in 2016, now represent a couple of satellites that follow one after another at the distance about 220 km along a single polar orbit. The object of study is the distance between them, which measured with the accuracy of 10 microns. Proper motion and orientation of satellites are recorded with the help of GPS receivers, accelerometers and star sensors. In addition, the satellites are equipped with corner reflectors for use in satellite laser altimetry. By changing the distance between satellites, it can be inferred about the changes in the gravitational field of the Earth. One of the basic tasks of this project is the representation of both permanent and time-varying components of the Earth's gravitational field. After the launch of the GRACE mission, many scientific groups began to process the obtained data. The last available solution dates September 2016.

A new stage in the development of Earth’s gravity models came with the launch of research satellite GOCE of the European Space Agency in 2009. Its distinctive feature was the record low orbit located in upper atmosphere at a height of 254 km. This feature allowed to obtain high spatial resolution; however, it led to the need to provide the satellite with a constantly working xenon ion engine to compensate for the effect of the atmospherical braking. The main useful load of satellite undertook 6 high-precision accelerometers. After working out the main observation program, the satellite had a significant fuel reserve, and the European Space Agency decided to continue the mission with a gradual orbit lowering by another 30 km. The orbit lowering further increased the spatial resolution and quality of the data obtained. Many scientists even called this the second mission. A 35 percent improvement in data quality was expected. Even in the first months of the mission after the publications of the data, it became clear that the accuracy of the results exceed the accuracy of all early observations including GRACE. More than 4 years later after fuel depletion the satellite was ocean dumping. The received data are currently processed by the world scientific community.

Today there are about a hundred geoid models, some of them are under development. The most popular and useful models are considered below.

- EIGEN-6C4 is a combined gravity field model calculated to a degree and order of 2190 using GRACE, Lageos, GOCE data and ground gravity measurements.
- TIM R5 is a gravity field model, calculated to a degree and order of 280 using only GOCE data.
- EGM2008 is a model of spherical harmonics of Earth’s gravity field, calculated to a degree and order of 2159 using different data.

In the current study, we consider the model EGM2008 in details. At the present, a group of scientists from the United States, headed by N.K. Pavlis, is engaged in development and evaluation of Earth’s geopotential model EGM2008. The produced model implementing different data is actively used in geodesy [8]. EGM2008 is a model of the spherical harmonics of the Earth's gravitational field, calculated to a degree and order of 2159 and containing additional coefficients to the degree of 2190 and order of 2159. This model replaced the EGM96. The EGM2008 includes gravity anomalies over a global equiangular 5-minute grid. This model is built based on surface data, takes advantages of satellite solutions for GRACE and contains improved altimetry-derived gravity anomalies calculated using PGM2007B (version PGM2007A) and dynamic ocean topography (DOT) models. The development of EGM2008 faced with some difficulties related to data insufficiency. For example, the altimetry-derived gravity anomalies in free air are combined with the corresponding values over the earth’s surface and supplemented with «completed» values for regions without any gravitational observations to form a complete global equiangular 5-minute grid of gravity anomalies in free air.

Thus, currently EGM2008 is one of the best models but still its accuracy is not enough for the high-precision levelling.
Many specialists work on the EGM2008 model local elaboration. A series of the most significant studies is given below.

V.Z. Ostroumov worked on development and evolution of methodology for determining the heights of tide gauge stations based on satellite observations using local and global quasi-geoid models from 2004 to 2013. In his articles are given the comparative characteristics of some global geoids and methods for their refinement on a local site. One of the articles is entirely devoted to the problem of increasing the accuracy of determining the altitude component of the coordinates obtained from GNSS data [1].

A local geoid model for the Novosibirskaya region was calculated in Siberian State University of Geosystems and Technologies [2]. The project was implemented based on a network consisting of 31 continuously operating reference stations evenly covering entire territory. The model is also obtained by refining the global model EGM2008. Geodetic and normal heights were taken from the materials by adjustment this network, but the normal heights of the base stations were not adjusted together, because it was obtained from isolated courses of geometric 1-4-order leveling. It is noteworthy that the project used ready-made commercial software.

Well-known A.N. Majorov model proved the possibility of determining normal heights with the accuracy of geometric levelling of III – IV order according to observations of satellite systems [5].

Vu Hong Cuong developed 12 variants of quasi-geoid models for Vietnam by combining the coefficients of high and low harmonics from the global geoid models GOCE-TIM4, EGM2008 and EIGEN-6C in Moscow State University of Geodesy and Cartography [4].

Algorithms of calculating height anomalies by combining gravity measurements, global gravity models, normal and geodetic heights were developed by D.A. Shogonbekova in 2015 in Kazakh National Research Technical University named after K.I. Sitpaev. Based on the results of works, the geoid model was developed for the territory of Kazakhstan. The model is based on the global model EIGEN-6C4 with a standard deviation of 0.037 m. [7].

There are other models developed for different local regions of the Earth’s surface but the determination of normal heights using these models also does not to exceed the accuracy of geometric levelling of III – IV order.

Conclusion
All works reviewed above were carried out with the use of data taken from the list of coordinates and heights of bench marks adjusted many years ago but with up-to-date satellite observations for these points. Due to permanent geodynamical and technogenic effects on bench marks their heights have to be re-determinate. Consequently, an insufficiency of effective data for geometric levelling is a week point in these works. In addition to out-of-dateness of reviewed data, it should be considered that at the moment there is a more advanced equipment that allows making measurements in a semi-automatic mode and reducing operator and other random errors manifold. As geometric levelling data are the standard for local elaboration of global geoid models, the key role in this process should be taken by procedure of levelling data updating.

Nevertheless a lot of digital geodetic levels imported to Russia, at the moment there is no regulations and standards for working with this device. However, there are works devoted to the influence of various sources of errors on digital geodetic levels and bar-code leveling rods. It can be noted that such geodetic levels are more sensitive to external factors and should be used with caution. In this connection, it is preferably to take into account the data of experiments on the behavior of digital geodetic levels in different environments. U.E. Fedoseev analyzed the existing regulations and standards in the area of geometric leveling, and also tried to interpret it to work with digital geodetic levels. In his paper [8], all the main problems that arise when working with this electronic device are reviewed in detail. A significant problem is also the metrological certification of digital geodetic levels. In connection with the absence of a bar-code leveling rod of the metric scale, control of meter and decimeter intervals of the leveling rod, assumed by the current standard for leveling, is a very sophisticated problem, and according to the article by N.K. Goligin, etc. [9] generally loses its
meaning, since the bar-code is read from more than 300 millimeter leveling rod section. The absence of a metric scale does not allow in the field environment to reject measurements containing gross errors, and the current regulations and standards does not contain suitable control procedures.

To solve our problem it is necessary to build a classical high-precision leveling network around the perimeter of the city, including the laying of missing geodetic marks. This type of leveling network is a universally recognized high-precision construction and will serve as a standard. The done extensive redundant observations of global navigation satellite systems on the points of this reference network will allow us to collect a sufficient amount of statistical information to determine the limits to applicability of the technologies themselves. This approach will allow to determine the minimum amount of measurements necessary to solve a particular problem. The collected data will be used in the preparation of regulations and standards for the work. When observational data processing, it is necessary to analyze several progressive mathematical algorithms taking into account the specific nature of new types of measuring instruments.

The solution of this problem is a priority, as it leads to a significant costs saving when geodetic support of civil construction, reduces the influence of the human factor and increases the automation of production processes.

The possibility of using satellite observations in high-precision levelling gives the new opportunities for Russian and foreign global navigation satellite systems.

References

[1] Ostroumov V Z 2013 Determination of Normal Heights of the Tide Gauge Stations' Benchmarks by the GNSS Data and the Quasigeoid Model in the Azov and Black Sea Region Geophrophy 3 20-23
[2] Obidenko V I, Opritova O A and Reshetov A P 2016 Working out of a technique of reception of normal heights in territory of the Novosibirsk region with use of earth gravitationnal model EGM2008 Vestnik SSUGT 1 (33) 14-25
[3] Kanushin V F, Karpik A P, Goldobin D N, Ganagina I G, Gienko E G and Kosarev N S 2015 The definition of gravity potential and heights differences in geodesy by gravimetric and satellite Vestnik SSUGT 3 (33) 53-69
[4] Vu C H 2013 Development of methodology for constructing a quasi-geoid from satellite measurements in Vietnam Extended abstract of PhD dissertation Moscow State University of Geodesy and Cartography Moscow
[5] Majorov A N 2008 Development of technology and creation of a quasi-geoid model using satellite data PhD dissertation Moscow State University of Geodesy and Cartography Moscow
[6] Dementjev U V 2012 Evolution of the theory and development of technology for determining the anomaly of gravity in complete topographic reduction doctoral dissertation Siberian State Geodetic Academy Novosibirsk
[7] Shoganbekova D A 2015 Development of algorithms for calculating heights anomalies and modeling gravimetric geoid of the Republic of Kazakhstan PhD dissertation Kazakh National Research Technical University named after K.I. Sitpaev Almaty
[8] Fedoseev U E 2010 The application of digital levels for high-precision work: theory, practice, problems Automated technologies of survey and design 2 (37).
[9] Goligin N H, Fedoseev U E and Cherepanov P A 2013 Perspectives for using measuring systems "digital level + bar-code leveling rod" News of Higher Educational Institutions Geodesy and air-photography 6 13-16.
[10] Pavlis N K, Holmes S A, Kenyon S C and Factor J K 2012 The development and evaluation of the Earth Gravitational Model 2008 (EGM2008) Journal of geophysical research 117 1-38.
[11] Fotopoulos G 2005 Calibration of geoid error models via a combined adjustment of ellipsoidal, orthometric and gravimetric geoid height data Journal of Geodesy 79 (1-3) 111-123
[12] Shapovalova K V 2014 *Int. youth scientific Conf. «Current issues of continuum mechanics and celestial mechanics – 2014» (Tomsk)* vol 1 (Tomsk: National Research Tomsk State University) p 135