DISCUSSIONS

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ON PROSPECTS OF ASTRONOMO-GEODESIC LEVELING FOR COORDINATE SUPPORT OF GEODYNAMIC AND TECHNOGENIC POLYGONS

The purpose of this work is to show the prospects and the need to continue work in Ukraine on the creation of anti-aircraft systems and astronomical geodetic leveling (a combination of astronomical and high-precision geometric leveling), using GNSS and instruments that provide accurate measurements of deviations of the temple 0.1 geodynamic landfills and man-made, which create for the construction of a height foundation for the construction and operation of extremely important facilities. The method of achieving the goal is provided by theoretical studies of existing methods of astronomical and geodetic leveling, modern methods of forecasting neotectonic processes, GNSS accuracy and geometric leveling. The main results – the possibility of using astronomical and geodetic leveling in the forecast of catastrophic deformations of the earth's surface, including earthquakes, control of the results of geometric and GNSS leveling.Scientific novelty: recommendations for the use of astronomical and geodetic leveling of specially created profiles on geodynamic landfills for forecasting neotectonic processes, GNSS control and geometric leveling using the geoidal component, the idea of synchronous observations using zenith systems in astronomical and geodetic leveling.

Key words: deviation of steep lines; zenith systems; GNSS; geodetic and orthometric heights; astrono-micalleveling.

Introduction

Analysis of literature sources shows that astronomical and geodetic leveling is the most accurate and efficient way to build a geoid profile on geodynamic and man-made landfills. Achieved accuracy of 0.1" determination of the components of the absolute value of the deviation of the temple at the point in less than half an hour, in addition to solving traditional problems of determining the shape of the Earth, allows the results of repeated astronomical and geodetic leveling of specially created profiles It is with these changes that modern scientific hypotheses associate catastrophic deformations of the earth's surface, in particular earthquakes.

The results of astronomical and geodetic leveling also allow to control geometric leveling by GNSS leveling and vice versa, to control and evaluate the accuracy of GNSS leveling by geometric results, which must be taken into account when developing methods for creating a regional altitude base of geo-technogenic polygons in orthometric, not normal system.

The idea of a control variant of the classical astronomical method for determining changes in the magnitude of the angle of inclination between points by synchronous observations, which greatly simplifies the preparation of data for measurements (does not require the addition of ephemeris stars), increases their efficiency and provides additional control and accuracy

Back in 1995, formulating the main directions of development of geodetic astronomy in the work [Krasnorylov, et al., 1995] the authors as a priority formulated the need to develop a method for determining the deviations of vertical lines with accuracy 0.1–0.2" to study the patterns of their changes, to establish links between astronomical and geodetic coordinate systems, bringing the measurement results to a certain era of reference and gravitational potential, the correct interpretation of the results of re-leveling in the study of neotectonic processes. The same accuracy is required in geodetic works for the construction and operation of modern unique structures and this is the accuracy provided by the method developed at the universities of Hamburg and Zurich, based on measurements using digital anti-aircraft systems. These devices should cause a real revolution in the study of GPP, because the accuracy of measurements increases almost immediately by an order of magnitude. The fact that, in the generally available technical literature, only two publications are available [Hirt, et al., 2006; Hirt, & Bürki, 2006], devoted to these issues, in our competitive time shows only the great practical significance of these works and their greater than just commercial value.

Presentation of the basic material

When performing engineering and geodetic works on surveys, creating a marking basis for construction, geodetic maintenance and control of installation work with relative accuracy of 10^{-4}–10^{-5} (up to 1 mm per 100 m), GPP within a construction or industrial site, at small angles in the geodetic network, was mostly considered homogeneous. However, the performance of engineering and geodetic works in the construction and installation of equipment on modern unique objects such as, for example, the Large Andron Collider, radio telescopes, observation of deformations on these and other unique structures, observation of neotectonic processes on geodynamic and man-made landfills, requires relative accuracy of measurements $1 \cdot 10^{-6}$ and above [Borovy, Burachek, 2017], special conditions for high-speed provision of high-speed railways, etc. The plans of the European Organization for Nuclear Research include the construction of a new collider 4 times larger and 10 times more powerful than the existing one. An even more powerful one plans to build China by 2030. One of the prerequisites for the implementation of these projects is to increase the accuracy of geodetic work during installation and operation. Already now only astronomical and geodetic leveling provides a height basis for the construction of modern accelerators, railway tunnels, for example, in the construction of a 57-kilometer tunnel through the mountain range of St. Gotthard C. [Hirt, & Bürki, 2006].

The dimensions of industrial sites of modern unique structures can be in the range of up to 100 km or more (for example, a new electronic collider), geodynamic – up to 30 and man-made landfills (the term was first proposed by Prof. A. L. Ostrovsky [Ostrovsky, 1978] – 5–15 km, (for example, on cascades of hydroelectric power stations, nuclear power plants). The state-of-the-art electronic total station Leica Absolute Tracer AT 960 (Fig. 1) provides the maximum error of measuring distances of 0.5 μm/m and determining spatial coordinates corresponding to an accuracy of 10^{-7} [leica-absolute-tracker-t960 (2020)]. Achieving such accuracy is impossible when designing the results of measurements on a reference ellipsoid by deployment and requires consideration of the inhomogeneities of the gravitational field, which are associated with the deflection of steep lines on the industrial site, which is the orientation of surveying instruments, even modern such as Leica Absolute Tracer AT 960.

Fig. 1. Leica AT 960

Modern Global Navigation Satellite Systems (GNSS), together with observations of the Earth's gravitational field (GSP), make it possible to determine planned changes in the coordinates relative to the center of mass of the Earth with an accuracy of – 1–2 cm, and relative changes in the coordinates of neighboring observation points with millimeter accuracy. The accuracy of the establishment of a terrestrial geocentric coordinate system of the order of 1 mm, the stability of points of the order of 0.1 mm [Minster, Wysession, et al., 2010; Plag, & Pearlman, 2009] millimeter accuracy in post-processing mode on the territory of Ukraine is officially guaranteed by the System Solution network [https://systemnet.com.ua (2019)]. This provides relative accuracy at distances from 10 to 100 km (RTK-RTN method) 1 1 10^{-7} and higher when operating even in standard RTK-RTN modes. At distances less than 10 km, when performing static measurements using special techniques [Tretyak, Sidorov, 2012], the maximum achievable accuracy may be limited by the accuracy of phase meters used in modern GNSS receivers – 1 %, which, when used in our time wavelengths, corresponds to the relative accuracy at distances from 1 km not less than 2 To achieve the maximum possible accuracy when equalizing such networks, it is also necessary to take into account the GPP of the Earth. Given that in general the GPP changes very slowly, even in the historical dimension, to solve reduction problems can be considered constant and use the results of its study to analyze the measurements of previous years, which in many cases (eg geodynamic studies) and represent a large, if not the greatest value. However, even theoretically, this is not always true. For example, the construction of hydraulic structures is accompanied by changes in the GPP, which according to the results of direct measurements are accompanied by changes in astronomical and geodetic deviations of the temple to 1.5" [Carlson, 1964], with the minimum desired accuracy of these changes at least 0.5". And, in general, the analysis of measurements of the last years at the analysis of dynamics of neotectonic processes demands the account of GPP at reduction of measurements.

Modern scientific theories [Zakharov, 2003; Karpenko, 2007, 2011] link possible catastrophic deformations of the earth's surface (including earthquakes), primarily with changes in the shape of equipotential surfaces. Such works, though only in theoretical terms, are being conducted in Ukraine. [Karpenko, 2011]. In this regard, it is also appropriate to mention the hypothesis that the law of universal gravitation, which in the first approximation for the spherical Earth was formulated by the genius I. Newton, for an ellipsoidal Earth is not associated with distance to the center of mass, as Newton, namely with curvature (radii) of equipotential surfaces.

In particular, it is argued that the surface of the world's oceans is not equipotential, the closest to equipotential are the Earth's surfaces, which coincide with 45 ° latitude [Zakharov, 2003; Karpenko, 2007]. In this regard, it is clear the need and importance of observing the temporal changes in the deviations of steep lines at stationary stations using devices such as NSO-2 [Ostrovsky, 1978] or modern electronic levels [Petrov, 2018]. These devices allow real-time recording on electronic media of changes in the deviation of the vertical line at the observation point, depending on the type of device with an accuracy of 1 to 0.05".

The construction of profiles of equipotential surfaces and the study of changes in their curvature was possible by traditional astronomical and geodetic methods, which developed as part of the task of determining the shape and size of the Earth's shape. This refers to astronomical and high-precision geometric leveling to determine the geometric and orthometric heights (heights of points on the earth's surface relative to the general-earth geocentric reference ellipsoid or geoid). Modern astronomical leveling now, as we have noted, allows independently, using zenith instruments [Hirt, et al., 2006], to determine the geoidal component of geometric heights – the height of the geoid relative to the reference ellipsoid, even with millimeter accuracy.

For comparison, the astronomical-gravimetric method allows to determine the geoidal component (relative to the quasi-geoid) with an accuracy of the order of a decimeter [Dvulit, Golubinka, 2009; Czarnecki, 2010], which in most cases does not meet the requirements of even hydrographic, especially engineering and geodetic works.

Prior to the GNSS era, the use of the astronomical and geodetic method of determining the shape and shape of the Earth was significantly limited by the fact that it could be used only at triangulation points of class I, almost only at Laplace points.

The use of GNSS completely removes the first problem that arises when using the astronomical and geodetic method – the need to determine B and L with the required accuracy. The accuracy of determining geodetic coordinates from GNSS measurements can reach an angular level of even 0.001". Therefore, the accuracy of determining the deviation of the temple by astronomical-geodetic method mainly depends on the accuracy of determining astronomical coordinates, especially latitude. The accuracy of astronomical measurements of latitude 0,2".

The second problem is that the liquid network of points with the necessary astronomical observations is also removed by the possibility of using anti-aircraft instruments, inertial systems, and so on. Impressive data on the accuracy of determining the absolute values of the deviations of the vertical line with a digital anti-aircraft camera TZK2-D, developed at the University of Hanover, are given in [Hirt, et al., 2006]. According to the results of research performed during the period 2003–2005, the accuracy of determining the deviations of the temple 0.05–0.08" is achieved in just 20 minutes of observations. As a result of the performed researches, 23 km of geoid profile with an accuracy of 1–2 mm were obtained, at distances between stations of 200 2000 m.

Fig. 2. DZCS system

Digital anti-aircraft cameras for measuring astronomical and geodetic deviations of the temple are used in the Baltic countries [Ansis Zarins, et al., 2016], Turkey [Albayrak, et al., 2019], Australia [Schack, et al., 2018].

It is a pity that the work on the creation of anti-aircraft cameras using CCD arrays, which began in Ukraine in the last century, has not found its further development and, moreover, even an understanding of the importance of this work. After all, in Ukraine in 2003, almost simultaneously with foreign ones, an experimentally tested and patented anti-aircraft system was developed, which provided UPC to determine the absolute value of astronomical and geodetic deviations of the temple at observation points ±0.4" [Borovy, et al., 2004].

However, one of the authors of the invention O. S. Goncharenko managed to defend his dissertation on astronomical leveling only for the second time in 2016 (the first defense took place in 2006).

The prospects for the use of digital anti-aircraft cameras (DZCS) in Russian-language sources in 2008 were indicated by [Glazunov, 2008]. However, as follows from the publication of the same author in 2017 [Glazunov, 2017], these works were not developed in Russia, as well as in Ukraine.

In the work [Serapinas, 2002] is very authoritative not only for the author prof. BB Serapinas claims that high precision geodetic gravity inertial systems are being developed and gradually implemented, which allow directly, in the shortest possible time, to measure the change in the increments of astronomical and geodetic deviations of the temple when moving from one point to another with an accuracy of 0.1".

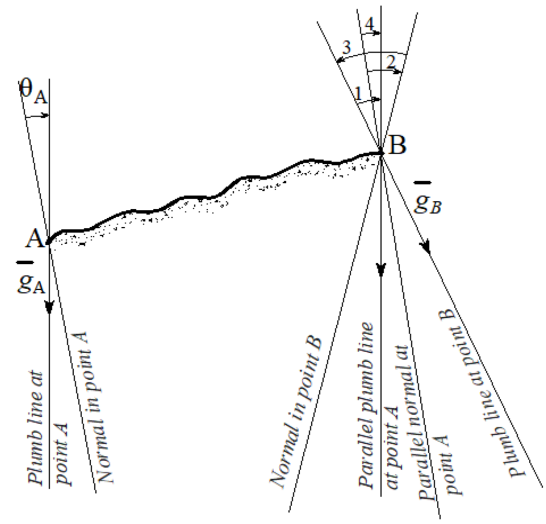

Fig. 3. Method of the difference in deviations of the plumb line

In Russia, a patent was registered in 2013 [Medovikov, Nigamatyanov, 2016], the authors of which claim that the patented method provides the accuracy of determining changes in the deviations of the temple 0.1 Unfortunately, the network has no data on other publications on the gravity method, except for relatively modern works [Staroseltsev, & Yashnikova, 2016], which provides a less optimistic assessment of the accuracy of the gravity inertia method using equipment developed by JSC Concern "Central Research Institute of Electric Equipment", St. Petersburg, however, for areas with highly dissected (variable) GPP, which are characteristic of geodynamic landfills . Yes, for the outskirts of Fr. Baikal figures are given $m\theta_{\text{cp}} = 1 \div 5"$. Approximately the same accuracy in determining the average values of astronomical and geodetic deviations of steep lines is provided by bilateral synchronous measurements of zenith distances [Dvulit, et al., 2019].

To explain the method of determining the absolute deviations of the temple by measuring the differences in deviations between adjacent points of the stroke, we turn to Fig. 3. In Fig. – vertical section (profile) along the line of astronomical leveling with azimuth – a_{AB}. Accordingly, all the lines in the figure are projections of the vertical line and the normal to the vertical section. In Figure the point A at which the known orthometric height, its geoidal component and the methods described above determined the projection of the absolute value of the deviation of the temple of a kind of permanent station. Point B is the point at which the difference of deviations of the temple between points A and B was determined, the projection of which on the profile is denoted (position 1 in Fig. 3). Position 2 in the figure – the convergence of the meridians -γ. Position 3 – θ_B. Position 4 – θ_A. Directly from fig. we find that when taken in Fig. 3 positive direction angles

$$\theta_B = \Delta\theta_{AB} - \theta_A + \gamma_{AB}, \qquad (1)$$

where $\gamma_{AB} = A_{BA} - A_{AB} - 180°$ – convergence of meridians, which, given the high requirements for accuracy – preferably not less than 0.1", to determine, from the appropriate formulas, for example [Savchuk, 2000].

Of course, all processing of measurement results, and in our opinion, should be carried out in a topocentric coordinate system with a strict transition to geocentric. Note that for the first time in the domestic literature, this was pointed out by L. P. Pellinen [Pellinen, 1978], based on the classic monograph [Moritz, 1979], and used in practice, when conducting observations on man-made landfill of the Dniester HPP under the leadership of prof. K. R. Tretyak [Tretyak, Sidorov, 2012]. Reduction of measurements on a reference ellipsoid, also, in our opinion, will remain only for cartographic works. The reason for this is the fact that traditional terrestrial reference geodetic networks are already, so to speak, replaced by networks of permanent and reference stations. This is due to the fact that these networks, as we have noted, provide instrumental accuracy of the GNSS method, already now, from 1×10^{-7} at distances of the order100 km to 2×10^{-7} at kilometer distances (RTK-RTN method). And this satisfies the accuracy in terms of almost all basic and topographic geodetic works, but also engineering and geodetic, excluding, and only in the case of unique structures, detailed planning and installation work. The advantages in the efficiency and estimated cost of GNSS works are beyond doubt. In engineering geodesy, in general, when performing both survey and planning works have long been used and are used special engineering and geodetic networks, which were equalized not in the state, but in conventional horizontal coordinate systems, the axes of which are oriented in the coordinate system of the master plan. If such a system is tied using GNSS measurements (at least one basis), then, orienting the zero limb of the electronic total station on this basis (with a known geodetic azimuth), you can directly, by measurements, obtain coordinates in the topocentric system, and then by strict mathematical formulas, to transfer to the geocentric universal terrestrial coordinate system WGS-84 and even further to any cartographic system, including USC 2000, as required by current regulations in Ukraine [Burak, Lysko, 2018] .

Consider the possibility of using the results of astronomical and geodetic leveling and to control GNSS leveling on geodynamic landfills. This possibility is directly provided by the integral formula of generalized astronomical leveling, which is an important component of Molodensky's theory [Molodsky, et al., 1960]. Let's write it in a modern interpretation:

$$\Delta H_{AM}^{\text{геом}} = \Delta H_{AM}^{ort} + (N_M - N_A) =$$
$$=[h]_{AM} + p_{ort} - \text{-}(N_M - N_A), \qquad (2)$$

where $\Delta H_{AM}^{\text{геом}}$ – the difference of geometric heights (heights relative to the geocentric ellipsoid, which in our time can be obtained by the results of GNSS leveling); ΔH_{AM}^{ort} – difference of orthometric heights (hypsometric part, which is obtained according to the geometric leveling from t. A to t. M, as the sum of measured excesses – corrected by orthometric correction $\text{-}p_{ort}$; $(N_M - N_A) = \frac{1}{\rho''}\int_A^M \theta dl$ – geoidal part, which is obtained by integrating the components of the deviation of the temple – along the line according to the results of astronomical leveling, which in turn are found by the formula:

$$\theta_i = \frac{1}{2}\left[(\xi_{i-1,i} - \xi_i)cos\alpha_{i-1,i} + (\eta_{i-1,i} - \eta_i)cos\alpha_{i-1,i}\right], \qquad (3)$$

where ξ and η are the components of the deviation of the temple in the meridian and the first vertical, respectively.

That is, if we know the components of the deviation of the temple at the starting point of course A, determined the differences in the deviations of the temple between adjacent stations of the course, determined from the geometric leveling of the excess in the course and orthometric correction, we can calculate the difference in geometric heights which can be compared with those obtained directly from the GNSS measurements. Conversely, for a certain length of geometric leveling strokes, it makes sense to control the amount of measured excesses in the course, using the difference in geometric heights obtained by GNSS.

Geometric leveling together with data on the vertical gradient of gravity allows determining the hypsometric component (orthometric height of the physical point of the Earth above the geoid). Theoretically, it is possible to accurately determine the amount of excesses (emphasize that not heights) during high-precision geometric leveling – using the most accurate, commercially available in Ukraine at present, the device, Leica LS15 – 0.2 mm per 1 km of double stroke [products / tsifrovoj- nivelir-leica-ls15-02-mm (2020)]. But this is without taking into account the errors that are made due to the accepted method of taking into account the vertical gradient of gravity, and errors in determining the orthometric height of the original reference frame.

As for GNSS leveling, it allowed to create a network of error points in determining the geometric heights which with a probability of 95 % do not exceed 10 mm [Darren Kerr, 2015]. Even in the last century, and not even in the United States, but in Poland, the accuracy of determining the amount of excesses, which corresponds to the leveling of the second class – [Cacon, et al., 1999]. According to the results of reprocessing and regular processing of more than two hundred state, academic, university and commercial networks of Ukraine, performed in GAO NAS of Ukraine, the accuracy of the solution using coordinate repeatability was for the horizontal component within 1.4 mm, for vertical – 3.63 mm [Ivashchenko, 2017].

From this it is easy to conclude that, theoretically, the length of the geometric leveling -, the sum of the excesses in which you can control the difference between the GNSS heights (geometric) – L (km) will be up to

$$L(\text{km}) = \left(\frac{m_h^{\text{ГНСС}}}{m_h^{\text{г.н.}}}\right)^2 = \frac{2^2_{\text{mm}}}{0{,}2^2_{\text{mm}}} \leq 100\ \text{km}. \qquad (4)$$

In reality, at present, surveying firms in Ukraine advertise the possibility of performing high-precision geometric leveling with an accuracy of 0.9 mm per km. And in this case, it makes sense to monitor the results of the GNSS leveling course of geometric leveling length of more than 5 km. This may require changes in the method of constructing a high-precision leveling network of geodynamic and technological landfills, which, as in most countries, should be developed in the orthometric system of heights based on GNSS leveling.

Here again we should emphasize the fact that according to the results of GNSS leveling, we can immediately obtain geometric or geodetic heights, depending on the accepted reference ellipsoid, and further, using astronomical leveling – geoid heights and orthometric heights. As we have already noted, the accuracy of determining the difference is theoretically possible and practically achieved the accuracy of determining the difference heights of the geoid at observation points using zenith systems, measured up to 2 millimeters [Hirt, et al., 2006]. To obtain the same results (orthometric heights and heights of the geoid) according to the results of traditional geometric and astronomical leveling, we still need to know the value of gravity at all stations of installation of tools and rails and the distribution of gravity on the GPP power line from reference to geoid on the final benchmark of the move. As for the first part of the problem, even existing gravimetric maps will suffice to solve it with sufficient accuracy throughout Ukraine with altitudes up to 0.5 km. As for the distribution of gravity on the GPP line of force to the geoid, this issue is at least still debatable and just astronomical and geodetic leveling using zenith systems may help to solve it, especially in the foothills and mountainous areas. That is, if the heights of the geoid, the geometric heights of the GNSS leveling, are known, it will be possible to assess the accuracy of the orthometric heights obtained by the method adopted in the country (see formula (4)).

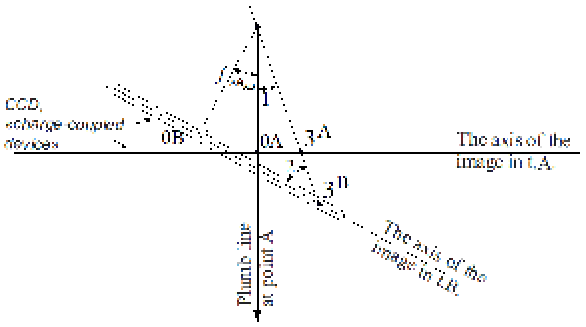

Fig. 4. Method of synchronous observations

In conclusion, we describe the idea of another, proposed by us, control variant of the astronomical method of determining the difference of deviations of the temple at two points using zenith systems, which simplifies both measurements and minimizes preliminary calculations and calculations of results at stations, increases accuracy compared to using inertial systems. The method uses the ingenious assumption of Eratosthenes of Cyrene about the absence of significant parallax of stars, even at distances equal to the diameter of the Earth. Suppose that at point A (permanent station, where measurements are performed by the classical astronomical and geodetic method determination of the absolute value of the deviation of the temple) and at the current point B are installed and brought into working position using an electronic level with an accuracy of 0.05" and oriented on the geodetic meridians of two anti-aircraft systems (Fig. 4). Errors in determining the elements of their internal orientation (focal length and coordinates of the main point), we can ignore. Perform at point A and at point B two simultaneous shots. Synchrony can be achieved with the help of accessories for signal separation, for example, type Splitter, requires a moment of at least 0.05 sec. In principle, the measurements on t. A can be performed not even continuously, but with some interval, which allows linear interpolation of the results. Given the fact that stellar parallax even during the year does not exceed 0.001" even on the diameter of the Earth, the directions of the star at points A and B, regardless of the distance between them and the orientation of the line – are parallel. In Figure O, the center of the lens of the anti-aircraft camera, OA and OB are the main points of the respective images at points A and B, ZA and ZV are the images of the star in the respective images. OAS = xA and OVZV = xB – abscissas of the image of the star on the corresponding pictures. Having measured these abscissas, we find the projection in the first vertical of the difference of the directions of the steep lines at points A and B by one of the obvious formulas, for example:

$$\Delta\theta_{\mathrm{AB}} = 90° - (arc\cos\left(\frac{f}{\sqrt{(f^2 + x_A^2)}}\right) + \\ + arc\cos\left(\frac{x_B}{\sqrt{(f^2+x_B^2)}}\right). \quad (5)$$

Accordingly, according to the ordinates of the star in both images we find the projections in the meridian of the difference of the directions of the vertical line at points A and B. Since each star allows us to compose an equation of type (5), it is possible, instead of studying the cameras (determining the elements of internal orientation and -$f_A, x_A^0, y_A^0, f_B, x_B^o, y_B^o$), to use the general form of equation:

$$\Delta\theta_{\mathrm{AB}} = 90° - (arc\cos\left(\frac{f_A}{\sqrt{f_A^2 + (x_A^0 + x_A)^2}}\right) + \\ + arc\cos\left(\frac{(x_B^o + x_B)}{\sqrt{f_B^2 + (x_B^o + x_B)^2}}\right). \quad (6)$$

Then, the results of observations of four or more stars will allow us to solve the problem with control and evaluation of accuracy.

Conclusions

1. As the literature analysis shows, astronomical leveling using anti-aircraft systems and GNSS is currently the most accurate and highly productive method for determining the heights of the geoid on the mainland.

2. Modern technology allows to determine this value with millimeter accuracy. And this, in turn, allows you to control the accuracy of determining the excesses in the course of geometric leveling, for example, even class II at a length of more than 5 km and vice versa – to control the accuracy of GNSS height measurements at shorter distances with the development of altitude basis landfills that are created for the construction and operation of unique facilities, respectively, to improve the methodology of construction of these landfills.

3. The results of repeated astrono-geodetic leveling by modern methods, specially created

individual profiles on geodynamic and man-made landfills, will allow with millimeter accuracy to determine changes in the shape of geoidal surfaces, namely changes in the radius of curvature of equipotential surfaces associated with catastrophic earth deformations. The idea of the control variant of the astronomical method of determination of a difference of deviations of a temple from synchronous measurements offered in article will allow to increase accuracy of a classical method, does not demand preliminary calculation of ephemeris of stars, etc.

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ПРО ПЕРСПЕКТИВИ АСТРОНОМО-ГЕОДЕЗИЧНОГО НІВЕЛЮВАННЯ ДЛЯ КООРДИНАТНОГО ЗАБЕЗПЕЧЕННЯ ГЕОДИНАМІЧНИХ ТА ТЕХНОГЕННИХ ПОЛІГОНІВ

Мета цієї роботи – теоретично обгрунтувати необхідність продовження робіт в Україні зі створення зенітних систем та астрономо-геометричного нівелювання з використанням Глобальних навігаційних супутникових систем (ГНСС) та приладів, які забезпечують точність вимірів відхилень виска 0,1– 0,2", для вивчення неотектонічних процесів як на геодинамічних полігонах, так і техногенних, які створюють для побудови геодезичної основи для будівництва та експлуатації надзвичайно важливих об'єктів. Методику досягнення мети забезпечено теоретичними дослідженнями існуючих способів астрономо-геометричного нівелювання, сучасних методів прогнозу неотектонічних процесів, точності ГНСС та геометричного нівелювання. Основні результати – встановлено теоретичну можливість використання повторного астрономо-геометричного нівелювання для оцінки змін радіусів кривизни еквіпотенціальних поверхонь, контролю результатів геометричного і ГНСС нівелювання. Наукова новизна: теоретично обгрунтовано можливість використання повторного астрономо-геометричного нівелювання спеціально створених профілів на геодинамічних полігонах для оцінки змін радіусів кривизни еквіпотенціальних поверхонь, з якими сучасні наукові гіпотези пов'язують можливість прогнозу землетрусів, контролю ГНСС і геометричного нівелювання з використанням геоїдальної складової на цих профілях, ідея синхронних спостережень з використанням зеніт систем при астрономо-геометричному нівелюванні.

Ключові слова: відхилення прямовисних ліній; зеніт-системи; ГНСС; геодезичні та ортометричні висоти; астрономічне нівелювання.

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