Accuracy of satellite leveling in studying geodynamical processes and deformations of structures

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Abstract. This article is focused on the need for satellite leveling in solving a number of scientific and industrial problems. Assessment of accuracy of satellite leveling developed by the author is presented for defining a point mark on the mounting horizon. It has been shown that elevations can be determined using satellite technology with the accuracy equal to the accuracy of determining plane coordinates. Possibility and viability of using satellite leveling has been justified for studying geodynamic processes and structures deformation.

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Introduction

In the context of rapidly developing deformations, building (structure) deformed state become pre-emergency or emergency in short time and can later lead to destruction if no measures are taken. In order to take prompt and adequate actions to protect an engineering object, it is first necessary to determine the dynamics of deformation and perform express diagnostics of deformation extent. Often subject to deformations are buildings located in central parts of major cities caused by a number of reasons, such as building new facilities at an unacceptably close distance to existing buildings, adding floors, changing groundwater regime as a result of pit opening for new construction, etc. Organization of geodetic work for identifying dynamics of deformation and for diagnosing extent of deformation in buildings in such cases is often hampered by the lack of direct visibility of observed points. To obtain the necessary information in a short time, regardless of visibility conditions and time of day, it seems appropriate to use satellite technologies along with tachymetry provided that required accuracy is achieved.

Another area of efficient use of satellite leveling (also provided that the required accuracy is achieved) is the studying of geodynamic phenomena on the surface of the Earth. As it is known, areas of tectonic faults can be seen on the earth's surface in the form of abnormal displacements in various directions, and thus adversely affect operational reliability of buildings and structures located in such areas. Until recently, influence of areas of tectonic disturbances on structures deformation has been neglected. However, with introduction of modern electronic geodetic measurement tools making it possible to determine points' coordinates with high accuracy and efficiency, more attention is being paid to studying such processes. Results of experiments [1,2,3] show that currently super intensive deformations of the earth surface occur related to areas of tectonic disturbance with speeds up to 50-70 mm per year. Spatial localization of these processes ranges from 100 m to 1-2 km. Such processes feature alternating and (or) pulsating nature. Authors of work [3] found in fault areas the geodynamical oscillatory motion of the earth's surface with a period of 30-60 sec. and 40-60 min. This contradicts the popular belief that plain (platform) areas feature low activity. Such processes may lead not only to the above-level deformations in buildings and structures located in this area, but often to emergency situations. It has been found that in the areas of tectonic faults damages to pipelines and emergency situations at boreholes occur. Studies show that more than 70% of emergencies on pipelines are associated with the areas of tectonic faults [1, 2].

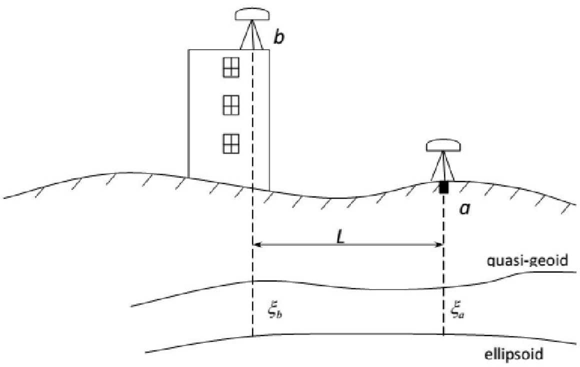
Results of geodetic studies of abnormal ground deformation in areas of tectonic disturbances formed the basis for a number of regulations.

The need for a wider use of satellite leveling, provided that high accuracy is achieved, is also caused by the extreme labor input needed for classical geometrical leveling in order to update the State Leveling Networks.

Main part

While the issue of precise definition of plane coordinates X and Y is practically assured, definition of points' high-altitude position requires special study. Thus, the mean square error in calculating coordinate increments by measurement of dual-frequency with satellite receivers is 3 mm+1-10-6D, where D is the distance between satellite receivers. However, it is believed that the height variations between the same points are determined with much lower accuracy [4].

Let us see what accuracy of height variation definition can be achieved using satellite technologies. Defining the accuracy of coordinates calculation using satellite technology is the subject of a number of works of Russian and foreign authors, including [2], [5-9]. Accuracy of height variation definition increases with decreasing horizontal distance L between satellite receivers down to 100-200 m (Fig. 1). It is with such horizontal distances between satellite receivers that measurement should be made for detailed study of local manifestations of geodynamic processes in areas of tectonic faults, as well as for studying deformation in structures.



In this case, geodetic heights h_{g_a} and h_{g_b} of points a and b are defined as the sum of normal heights h_{h_a} and h_{h_b}, and heights of the quasi-geoid above the reference ellipsoid

$$h_{g_a} = h_{h_a} + \xi_a;$$

ξ_a and ξ_b

$$h_{g_b} = h_{h_b} + \xi_b,$$

In case of equal heights of quasi-geoid ($\xi_a = \xi_b$) in points a and b, and insignificant distance between these points, differences between geodetic and normal

$$h_{ab} = h_{g_b} - h_{g_a} = h_{h_b} - h_{h_a}$$

Consequently, accuracy of defining the value of height variation will depend on the accuracy of defining coordinate $\Delta x_{ab}, \Delta y_{ab}, \Delta z_{ab}$ differences using satellite leveling.

Let us show accuracy assessment of height variation calculation for such a case using the formula

$$h = \sqrt{x^2 + y^2}\cos b + z\sin b - a'\sqrt{1 - e^2\sin^2 b}, \qquad (1)$$

Formula (1) has been obtained from relation

$$h = (N + h_g)\cos^2 b + (N + h_g)\sin^2 b - e^2 N\sin^2 b - N(1 - e^2\sin^2 b),$$

where x, y, z are Cartesian coordinates of the points where receivers are installed; b are geodetic latitudes; a' is semi-major axis of the Krasowski ellipsoid; e^2 is the first ellipsoid eccentricity; $N = \frac{a'}{\sqrt{1 - e^2\sin^2 b}}$ is the radius of curvature in the prime vertical; h_g are geodetic heights of satellite receivers installation points.

According to formula (1), let us represent the height difference h_{ab} as follows:

$$h_{ab} = h_b - h_a = \sqrt{x_b^2 + y_b^2}\cos b_b - \sqrt{x_a^2 + y_a^2}\cos b_a + z_b\sin b_b - z_a\sin b_a - a'\sqrt{1 - e^2\sin^2 b_b} + a'\sqrt{1 - e^2\sin^2 b_a}. \qquad (2)$$

If the distances between satellite receivers are small, then we can assume that Accordingly, expression (2) can be written as

$$h_{ab} = (\sqrt{(x_a + \Delta x)^2 + (y_a + \Delta y)^2} - \sqrt{x_a^2 + y_a^2})\cos b + \Delta z\sin b, \qquad (3)$$

where $\Delta x, \Delta y, \Delta z$ is coordinates increment between points a and b.

Next, let us expand formula (3) into a Taylor series. For assessing accuracy, it is sufficient to use expansion terms of first order of smallness. As a result, formula (3) can be reduced to:

$$h_{ab} = \frac{x\Delta x + y\Delta y}{\sqrt{x^2 + y^2}}\cos b + \Delta z\sin b \qquad (4)$$

The previously performed assessment of calculating accuracy of height variations using satellite technology at small distances between observed points [4, 10] shows that the accuracy of calculating height variations is practically independent of defining coordinates of the points themselves. The main factor affecting the accuracy of measuring height variations is the error of coordinates increments. Consequently, in view of practical equality of points latitudes, from formula (4) we can get

$$dh_{ab} = \frac{xd(\Delta x) + yd(\Delta y)}{\sqrt{x^2 + y^2}}\cos b + d(\Delta z)\sin b. \qquad (5)$$

From differentials, we can proceed to the mean square errors

$$m_{h_{ab}}^2 = \frac{x^2 m_{\Delta x}^2 + y^2 m_{\Delta y}^2}{x^2 + y^2}\cos^2 b + m_{\Delta z}^2\sin^2 b. \qquad (6)$$

Given that in determining the coordinates satellite receivers have equal mean square errors equation (6) can be written as follows:

$$m_{h_{ab}}^2 = m_\Delta^2\cos^2 b + m_\Delta^2\sin^2 b = m_\Delta^2.$$

or

$$m_{h_{ab}} = m_\Delta$$

Conclusions

Thus, accuracy of determining the height variations is equal to accuracy of plane coordinates. The mean square error of positioning using modern satellite receivers is ~ 3 mm. This accuracy is sufficient for studying geodynamic processes and deformations in structures.

The main disadvantage of this conclusion is the fact that coordinates increments $\Delta x, \Delta y$ and Δz are dependent, as they have been derived from the same measurement results.

Analysis of the scientific literature shows that correlation coefficients between the errors in measurements $\Delta x, \Delta y$ and Δz have not been studied. However, experimental studies were made of the accuracy of calculated values, i.e., differences of heights and lines lengths, which confirms veracity of accuracy assessment performed by us.

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