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APPLICATION OF PHOTOGRAMMETRIC METHODS FOR GEOTECHNICAL MONITORING OF EMERGENCY BUILDINGS AND STRUCTURES

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Statement of the problem. One of the relevant scientific and technical issues for improving the state-of-the-art and advanced monitoring methods is alarm construction (including in the minds of ordinary minds) with the emergence of uncompromising objects, and the future of unfinished control. It is quite common that conditions arise when it is not possible to perform a full-fledged monitoring of certain types of deformations of building structures by means of traditional methods. It is required to develop universal, superior and manual methods for the control of different geometric parameters of structures for taking timely measures to ensure the stability and stability of the structure and enabling the transition of the structure in the interconnection of the robotic mill as well.
Results. All of the considered methods of statistics of the ways to control the output and have been revised based on the maintenance and repair of the conserved Voronezh nuclear power plant for heat supply.
Conclusions. The methods of calculating deformations and the quality of the preparation of alarm constructions for metric photography allowance to carry out repeated monitoring of the technical mill with the necessary accuracy.

Keywords: photogrammetry, deformation, roll, settlements, monitoring.

Introduction. According to the analysis of scientific literature and the experience of construction organizations, while monitoring the stress-strain of building structures, it might be necessary to work in very cramped conditions when due to a small distance to the object, it is not possible to set up a geodetic device or image sharpness on the device [2, 17, 9].

At the same time, modern research in the field of deformation control commonly focuses only on measuring settlements, rolls and horizontal displacements of bases and foundations, and not on controlling the geometric parameters of individual building structures [1, 3—5, 7—11, 13—16, 18, 20].

Meanwhile, according to SP (СП) 22.13330.2011 (clause 5.6.4) and SP 126.13330.2012 (clause 8.6), in the process of monitoring a structure under construction, in addition to settlements, rolls and displacements, torsions, deflections of structures, their technical condition and other parameters should be monitored whose composition depends on the aim and construction conditions of the premises. This has become particularly relevant in the recent years as the world is building unique structures on a growing scale that are distinguished by non-standard structural solutions, the use of new construction technologies and building materials whose behavior under the influence of various loads and aggressive environmental influences has not yet been sufficiently studied.

It should also be remembered that there is a large number of unfinished and suspended construction projects in the country. While controlling deformations in such objects, in the absolute majority of cases, traditional measurements are curtailed by the tightness of operating conditions, the uneven effect of various meteorological factors (illumination, temperature, refraction, turbulent air flows) and deformation of structures and soil in the immediate proximity of the structures.

All of these caused a number of significant shortcomings that are found in the system for monitoring the safety of construction sites. Firstly, in modern construction practice, there is commonly no constant monitoring of the technical condition of the object and the neighboring territory. Only a selective examination of the technical condition of individual objects is commonly carried out. Secondly, up to now, no criteria have been developed for a comprehensive assessment of the state of an object in each period of time. Thirdly, the construction customer often lacks an understanding of the need for such continuous integrated monitoring, which causes a lack of funding for this type of work.

Under such conditions, it is impossible to conduct a full-fledged monitoring of certain types of deformations of building structures by means of traditional methods. It is required to develop universal, reliable and convenient methods for monitoring various geometric parameters of the structure for taking timely measures to ensure the stability and durability of the structure in order to exclude the transition of the structure to a partially operable or emergency state.

Therefore one of the urgent scientific and technical problems in construction is currrently the improvement of methods for monitoring the state of building structures (including in cramped working conditions) during the construction of unique structures and objects of unfinished construction, ensuring reliable control of their quality, stability and safety.

Thus the authors are seeking to make use of the capabilities of metric photography when observing the deformations of building structures, individual nodes and parts located in hard-to-reach places or confined working conditions.

1. Control of deformations and quality of manufacturing of building structures. While determining deformations and controlling the manufacture of building structures along the *Y*-axis (Fig. 1, 2) in confined working conditions, the photogrammetric method with a sha-dow projection of a grid of wires stretched in front of the investigated surface can be employed (Fig. 3).

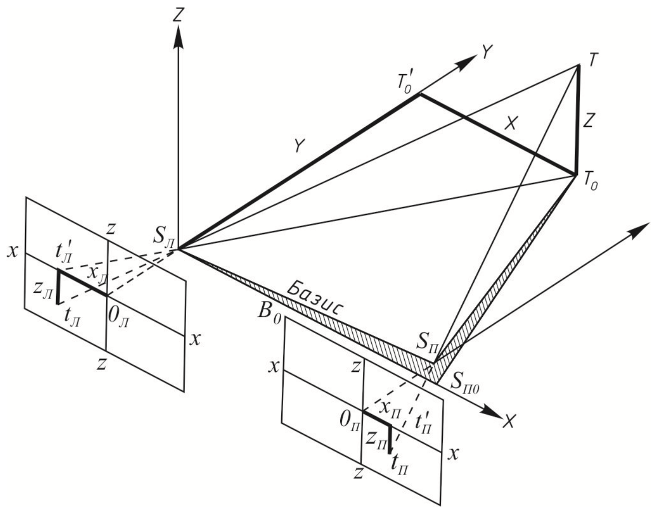


Fig. 1. Scheme for identifying deformations of building structures by means of the photogrammetric method (location of axes in ground photogrammetric survey)

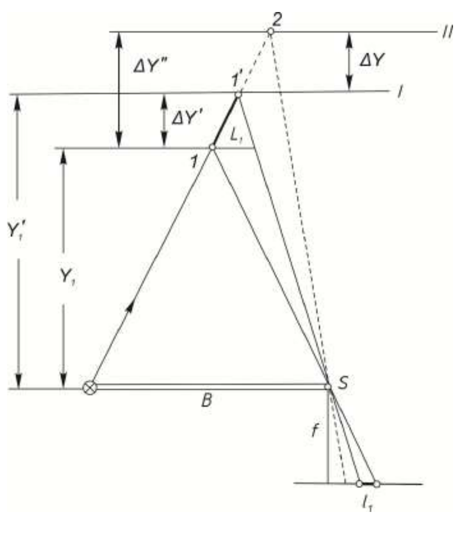


Fig. 2. Identifying the deformations by means of the photogrammetric method with shadow projection of wire mesh: 1 is a wire; I—II is the position of the planes of the structures; 1 / and 2 is the shadow from the wire on the planes of the structure I and II

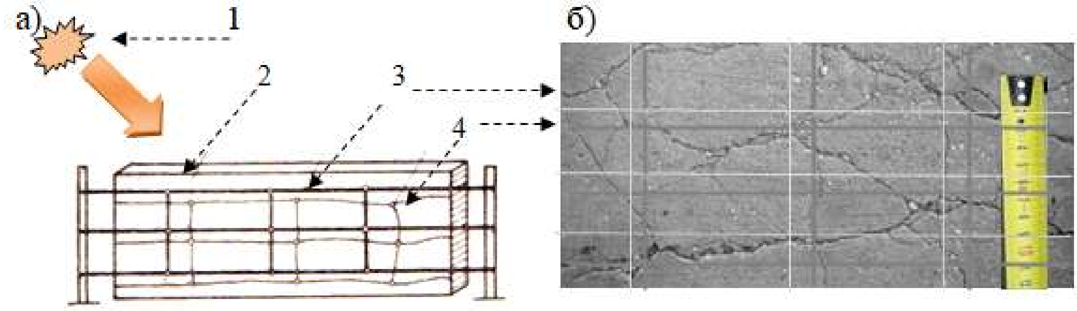


Fig. 3. Obtaining a shadow projection of wires for identifying the deformations and geometric shape of the surface of a building structure: a) a scheme for identifying the deformations of building structures using the shadow projection method; b) measuring the deflection of the wall on the chemical water purification (CWP) building; 1 is a light source; 2 is the investigated construction; 3 is the wire mesh; 4 is the shadow projection of the mesh

Shadows ca n also be used to define the geometric shape of the investigated surface.Prior to launching the survey, a baseline is split in an accessible place along the structure. The photographing of the building structure is taken from one end of the base, and a light source is installed at the other end.

The image shows the wire 3 and its shadow 4 (Fig. 3). The distance of the points of the surface of the investigated part from the wire is denoted by $\Delta Y'$.

$$\Delta Y' = \frac{L_1 Y'}{B} = \frac{l_1\left(Y_1 + \Delta Y'\right)Y_1}{Bf} = \frac{L_1 Y_1^2}{Bf}\left(1 + \frac{\Delta Y'}{Y_1}\right). \tag{1}$$

If the wire is stretched near the surface of the investigated part, formula (1) can be simplified

$$\Delta Y' \approx \frac{L_1 Y_1^2}{Bf} = \frac{-\Delta p_1 Y_1^2}{Bf}, \tag{2}$$

where $l = \Delta P_1$.

Using the calculated $\Delta Y'$, it is possible to construct a surface profile in a given direction or draw horizontals of equal values of $\Delta Y'$, as well as make an orthographic projection of the surface of the current vertical displacements of the building structure (Fig. 4).

If, under the action of deformations, the controlled surface has moved from position I to position II (Fig. 1), using formula (2), it can be written

$$\Delta Y'' = \frac{l_2 Y_1^2}{Bf} = \frac{-\Delta p_2 Y_1^2}{Bf}, \tag{3}$$

In this case, the deformation along the Y-axis of a point on the surface of the structure will be equal to

$$\Delta Y = \Delta Y'' - \Delta Y' = \frac{-\Delta p_2 Y_1^2}{Bf} + \frac{\Delta p_1 Y_1^2}{Bf} = \frac{-\Delta p Y_1^2}{Bf}, \tag{4}$$

where Δp is the distance in the picture between the shadow images.

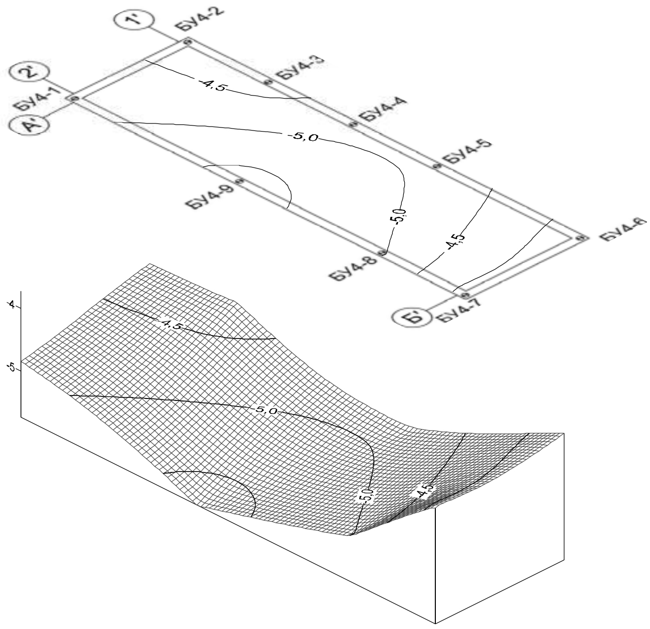


Fig. 4. Orthographic surface projection of current vertical offsets building structure I—II

For identifying deformations, photography is performed twice — before and after the deformation. In the process of measurements, the starting point for determining Δp is the count on the wire image.

The advantage of the suggested method of shooting with a shadow projection of the grid is that photography is conducted from one convenient standing point, while it is possible to increase the accuracy of identifying ΔU by increasing the shooting , i.e., the distance between the camera and the light source.

In order to the parameters of chips, irregularities, grooves of individual building structures (Fig. 5) and control their development, the method of stereo-shadow photogrammetry can be used. The scheme of the research principle is shown in Fig. 6.

Fig. 5. Failure of the structure of facing panels

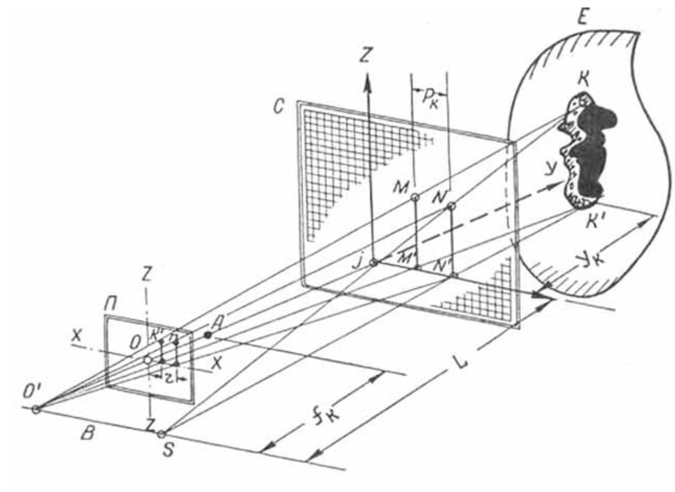


Fig. 6. Stereo-shade photogrammetry (general research principles): *P* — plane of the photograph; *A* — optical center of the camera lens; *C* — mesh; *E* is the object of research. *X, Y, Z* — spatial coordinates and their axes; *B* — beam; *S* — illuminator; fk is the focal length of the camera; 0—0 '- main optical axis of the camera; *L* is the distance from the point of convergence of the rays to the plane of the grid; *K* — *K* '— coordinate points of the object of study; P_k — parallax of point *K*; *r* — converted in the photograph the value of the parallax point *K* to be measured; *j* is the point of intersection of the main optical axis of the camera with the grid; *N, N'* are the projections of coordinate points *K* and *K'* on the grid; Y_k is the distance from the coordinate point *K'* of the research object

For this research, it is necessary to set up a large-format camera on a tripod and use a tacheometer to orient it accurately in space. The optical axis of the camera should be oriented strictly perpendicular to the plane of the grid which is placed between the camera and the structure.

The camera must be rigidly connected to the base where the illuminator is set up. A grid with an orthogonal filament system is placed in front of the camera at a fixed distance. While illuminating a building structure, the light passes through the mesh and a projection of this mesh is displayed on the surface of the structure. In addition, the shadow pattern of each shadow thread forms the cross-sectional profile of the investigated section of the structure.

In the resulting images, measurements can be made and the spatial coordinates *X*, *Y* and *Z* of the selected points along the profile line can be obtained. Based on the data, it is possible to construct a mathematical model of the geometric parameters of the structure of the studied object along the selected sections. The requirements for the measurement accuracy of *Y* can be identified based on the well-known formulas (5 and 6).

$$m_{\Delta X} = \Delta X \sqrt{\left(\frac{m_Y}{Y}\right)^2 + \left(\frac{m_{\Delta X}}{\Delta X}\right)^2 + \left(\frac{m_f}{f}\right)^2}, \quad (5)$$

$$m_{\Delta Z} = \Delta Z \sqrt{\left(\frac{m_Y}{Y}\right)^2 + \left(\frac{m_{\Delta Z}}{\Delta Z}\right)^2 + \left(\frac{m_f}{f}\right)^2}. \quad (6)$$

Depending on the operating conditions, the accuracy of measuring the distances m_Y can be defined as the specified accuracy of determining the deformations $m_{\Delta X}$, $m_{\Delta Z}$ or, the accuracy of measuring the displacements $m_{\Delta x}$, $m_{\Delta z}$ on the images.

In the first case, we will have:

$$m_Y = Y\frac{m_{\Delta X}}{\Delta X}, \quad (7)$$

In the second case:

$$m_Y = Y\frac{m_{\Delta x}}{\Delta x}, \quad (8)$$

where ΔX and Δx are respectively the maximum values of the deformations of the points of the structure and the measured displacements in the image; $m_{\Delta X}$ is the error in determining the deformations ΔX due to the influence of errors in identifying the distances.

The calculated value of $m_{\Delta X}$ in the formula (7) should be 2—3 times less than the specified one, so that the distance errors do not impact the accuracy of identifying the deformations. Accordingly, the calculated value of $m_{\Delta X}$ for the same reason should be 2—3 times less than the measurement accuracy of displacements.

The requirements for the accuracy of determining the focal length of the camera is given by the formula (9): where ΔX and Δx are the maximum values of the deformations of the points of the structure and the measured displacements in the photograph, respectively; $m_{\Delta X}$ is the error in determining the deformations ΔX, due to the influence of errors in determining the distances.

The calculated value of $m_{\Delta X}$ in the formula (7) should be 2—3 times less than the specified one, so that the distance errors do not affect the accuracy of determining the deformations. Accordingly, the calculated value of $m_{\Delta X}$ for the same reason should be 2—3 times less than the measurement accuracy of displacements.

Requirements for the accuracy of determining the focal length of the camera is given by the formula (9):

$$m_{\Delta X} = \Delta X\frac{m_f}{f}, \quad (9)$$

hence

$$m_f = \frac{m_{\Delta X}}{\Delta X} f = \frac{m_{\Delta x}}{\Delta x} f. \quad (10)$$

So, e.g., at $m_{\Delta x} = 0.002$ mm, $m_{\Delta X} = 0.50$ mm; $f = 200$ mm we will get $m_f = 0.8$ mm.

2. Identifying the deformations of high-rise buildings. Deformation control and executive geodetic survey of high-rise buildings in close-built conditions are often a difficult and time-consuming task. In this case, a stereophotogrammetric control method can be employed.

Field work in this case does not cause any difficulty and entails standard photographing of the structure from two permanently fixed points and a number of auxiliary geodetic measurements.

The methods of cameral processing of the obtained images can cause a certain degree of complexity.

If the structure is depicted in the image symmetrically to the *z*-axis of the image, by measuring the coordinates of four lateral points 1—4 on a single image (Fig. 7), it is possible to determine the partial rolls of the structure V_A and V_B (Fig. 8).

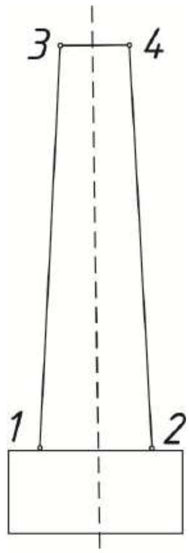


Fig. 7. Location of points for identifying the inclination of the chimney

Based on Fig. 7 and 8 we can write:

$$V_A = \left(\frac{x_3 + x_4}{2} - \frac{x_1 + x_2}{2} \right) \frac{Y_A}{f} = \frac{Y_A^{'}}{f} \Delta x_A, \tag{11}$$

$$V_B = \left(\frac{x_3^{'} + x_4^{'}}{2} - \frac{x_1^{'} + x_2^{'}}{2} \right) \frac{Y_B}{f} = \frac{Y_B^{'}}{f} \Delta x_B, \tag{12}$$

In this case, the total roll value can be found both graphically and analytically.

While shooting multiple subjects at the same time, their images might appear on the edges of the image resulting in perspective distortions in the image.

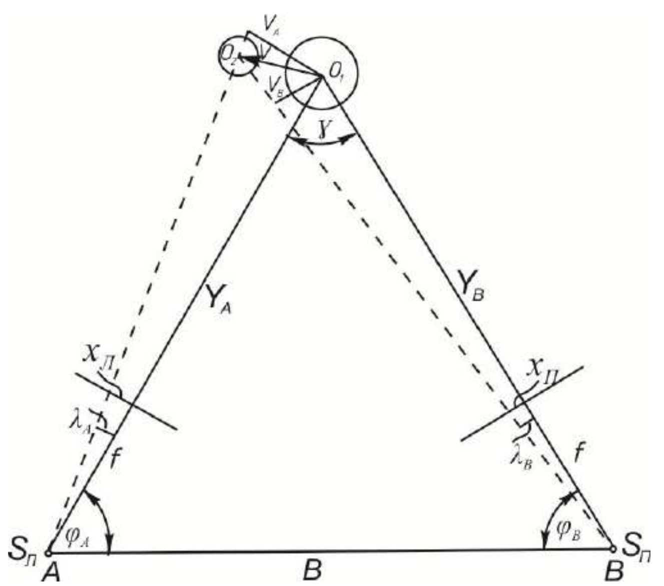


Fig. 8. Identifying the inclination of the chimney when it is located in the image symmetrically to the *ZZ* axis

In order to exclude a forward-looking error, a correction should be introduced into formulas 11 and 12:

$$\delta x_0 = \frac{\Delta x^2 x_{cp}}{4f^2\left(1+\frac{x_{cp}^2}{f^2}\right)}, \tag{13}$$

$$x_{cp} = \frac{x_1 + x_2}{2}, \qquad \Delta x = x_1 - x_2. \tag{14}$$

Given the correction, the original formula for identifying the partial roll (11) will take the form:

$$V_A = \left(\frac{x_3 + x_4}{2} - \delta x_{0B} - \frac{x_1 + x_2}{2} - \delta x_{0H}\right)\frac{V_A}{f} = \left[\left(x_{cpB} - \delta x_{0B}\right) - \left(x_{cpH} - \delta x_{0H}\right)\right]\frac{V_A}{f} =$$
$$= \left[\left(x_{cpB} - x_{cpH}\right) - \left(\delta x_{0B} - \delta x_{0H}\right)\right]\frac{V_A}{f} = \frac{V_A}{f}\left(\Delta x_A - \delta x\right), \tag{15}$$

where δ_{xB} , δ_{x0H} are corrections for perspective distortion for high and low points of a structure; $\Delta\ \delta_{xA}$ is the measured value of the roll of the structure in the image; $\boldsymbol{\delta_x}$ is the correction in the measured declination value.

The mean square error in determining the roll according to formula (15) will be equal to

$$m_{V_A}^2 = \left(\frac{Y_A}{f}\right)^2 m_x^2 + \left(\frac{\Delta x_A}{f}\right)^2 m_{Y_A}^2. \tag{16}$$

It should be remembered that the accuracy of identifying the partial roll V_A is affected by the error in determining the distance Y_A. The distance can be found in various ways. With a roll

ΔX = 0.1 — 0.3 m, it is enough to determine the distance graphically. For large values of the roll, an analytical calculation is required.

While determining the distance from n images

$$\frac{m_Y}{Y} = \sqrt{\left(\frac{m_B}{B}\right)^2 + \left(\frac{1.4m_\varphi}{\rho\sqrt{n}}\right)^2}, \tag{17}$$

hence the requirement for the accuracy of measuring the basis for various values of the roll is identified:

$$\frac{m_B}{B} = \sqrt{\left(\frac{m_Y}{Y}\right)^2 + \left(\frac{1.4m_\varphi}{\rho\sqrt{n}}\right)^2}. \tag{18}$$

Depending on the method of controlling the external orientation elements, the roll of the structure can be given by the difference between the coordinates of the upper and lower axes of the structure with a relative root-mean-square error of 1/6000 — 1/16000 of the height of the structure.

However, it should be remembered that the accuracy of determining the roll might be somewhat reduced in the case of the image of the structure along the edges of the image.

It is sensible to apply the spatial roll to apply the convergent case of shooting at a convergence angle close to 90°. It must also be ensured that the image of the structure is located closer to the central part of the image. While the roll direction is in a plane parallel to the datum, the normal survey should be used. In this case, the roll of the structure can be determined with an error of up to 1/30000 of the height of the structure.

Route and block surveys.

While controlling deformations on extended objects, it is better to perform block or route survey of the object (Fig. 9).

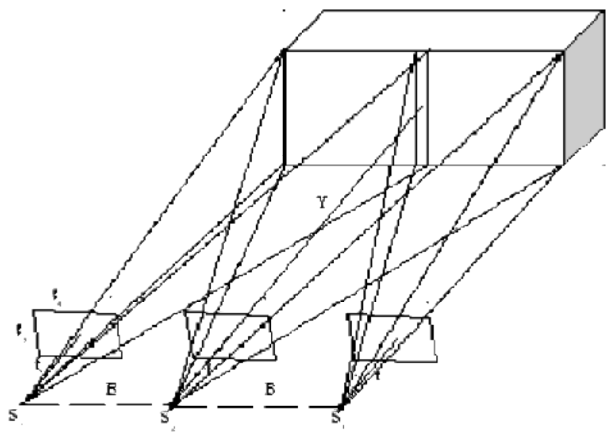


Fig. 9. Route survey of the extended object

With this type of survey from several stereopairs obtained by means of a normal or equally inclined survey method, the survey should be conducted with the expectation that additional stereopairs have an overlap area of 60 %.

If the object in the image is not completely located in the height, a block survey should be performed involving several strips (Fig. 10). At the same time, several parallel routes are formed, having a lateral overlap of 20—30 % or more. If there is not enough space for installing cameras, shooting can be performed from different heights, e.g., from the ground and from the roof of a building.

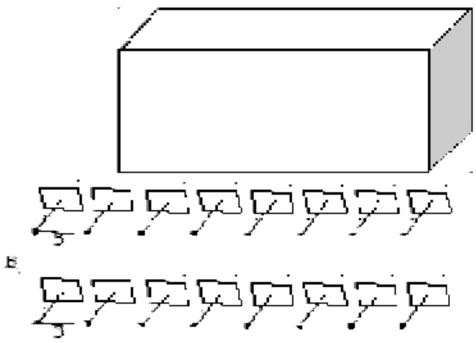


Fig. 10. Block survey of the object

If separate sections of the structure are not displayed on the stereopair, a survey should be performed from additional bases (Fig. 11).

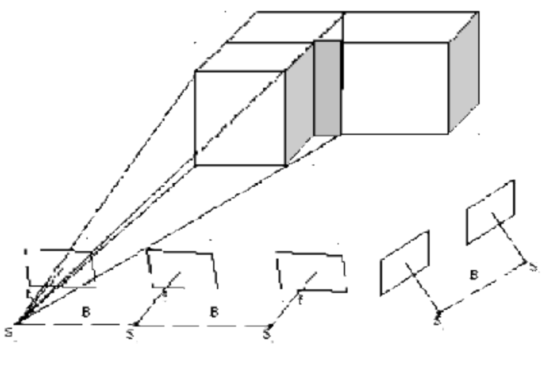


Fig. 11. Shooting of invisible points of the object from additional bases

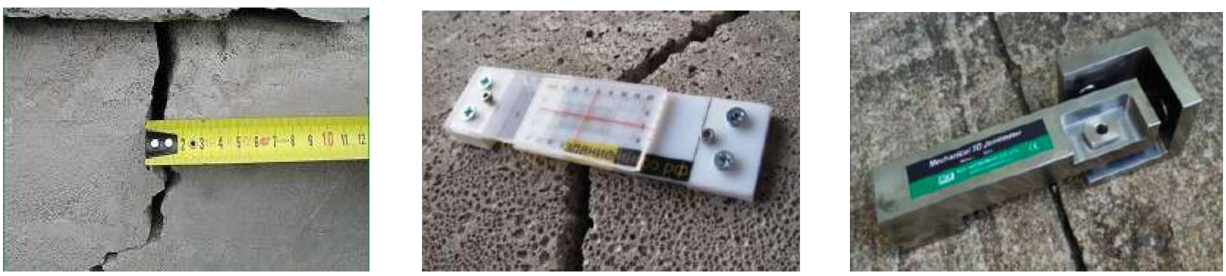
While processing the results of measurements of the roll increments on site, the above technique for any case of shooting and as well as all of the formulas provided can be used.

In practice, for this type of work, it is convenient to use stereophotogrammetric setups consisting of two cameras fixed on a rigid base (Fig. 12). For each type of work, the basis can change or remain unchanged. Shooting is performed simultaneously with two cameras. The optical axes of the cameras are parallel to each other and perpendicular to the base.

Fig. 12. Stereophotogrammetric installation for control of deformations of building structures [Source URL: https://sapr.ru/article/24694 (reference date 18.04.21)]

3. Methods for measuring the dynamics of sedimentary cracks. In addition to identifying the magnitude of deformations using photography, an accurate documentary control of the dynamics of the development of sedimentary cracks can be performed.

Traditionally, crack propagation is monitored by means of measuring with the simplest instruments (Fig. 13) and using beacons of various designs. The depth of the cracks is determined using needles and wire probes.



a) b) c)

Fig. 13. Traditional methods of controlling crack development:
a) a tape measure; b) an electronic fracture tester «Mayak ZI-2U»
[Source URL: здание-инфо.рф/2012/03/(reference date 18.04.21)] c) 3D crack measurer 6310
[Source URL: https://monsol.ru/mechanicheskiy-3d-treshinomer-6310/(reference date 18.04.21)]

However, in the presence of a large number of cracks of various depths and directions (Fig. 14), as well as in the case of hard-to-reach cracks, the use of traditional methods is not always possible.

Fig. 14. A network of numerous vertical and horizontal cracks of various depths and directions which are difficult to control by means of traditional methods

In these cases, metric photography can also be employed to measure cracks. Shooting cracks can be performed with a conventional amateur camera. In order to identify the size of cracks, it is necessary to know the scale of the image in the image which is determined according to the size of standard parts (brickwork, ruler). The accuracy of measuring the direction and size of cracks can be increased if there are marking points along the edges of the crack. To eliminate perspective distortions, one should strive to install the camera parallel to the plane of the structure under study.

To determine the increments of cracks, it is necessary to repeat the survey from the same point so that the images of subsequent cycles have a scale equal to the scale of the first image. To do this, it is necessary to securely fix the photographing points.

The crack increment can be found by stereoscopic measurement of the displacement in the image Δx, (Δz), as is done with the photogrammetric method for determining deformations with subsequent calculations using formulas (19) and (20).

$$\Delta X = X' - X = Y\frac{x'}{f} - Y\frac{x}{f} = Y\frac{\Delta x}{f} = \Delta x M, \tag{19}$$

$$\Delta Z = Z' - Z = Y\frac{z'}{f} - Y\frac{z}{f} = Y\frac{\Delta z}{f} = \Delta z M, \tag{20}$$

where X, Z and X', Z' are the coordinates of the points in the image before and after the deformations.

4. Features of processing ground images when monitoring the state of building structures. Stereopairs and single ground images of building structures are processed according to the standard technique, direct, inverse photogrammetric intersection, as well as the construction of strip and block phototriangulation. However, it should be remembered that the photo shows only the space in the camera's field of view. In this regard, the identification of the exact position and orientation of the camera should rely on well-known coordinates of the control points located throughout the measurement area.

Another feature of the processing of ground images is that the coordinates of the photographing centers and the control directions between the points of building structures, the distance between the points and the length of the photographing base can be additionally used as reference points.

So, e.g., the distance *D* between two points of a building structure *i* and *j* can be defined as a function of the coordinates of these points:

$$D_{ij}^2 = \left(X_i - X_j\right)^2 + \left(Y_i - Y_j\right)^2 + \left(Z_i - Z_j\right)^2. \quad (21)$$

The distance *D* between the photographing point *S* and the point *i* of the object can be given by the expression:

$$D_{si}^2 = \left(X_s - X_j\right)^2 + \left(Y_s - Y_j\right)^2 + \left(Z_s - Z_j\right)^2. \quad (22)$$

The length of the photographing basis *B* can also be determined using the coordinates of the two projection centers:

$$B^2 = \left(X_{s2} - X_{s1}\right)^2 + \left(Y_{s2} - Y_{s1}\right)^2 + \left(Z_{s2} - Z_{s1}\right)^2. \quad (23)$$

If the points *i* and *j* belong to the same vertical plane, (e.g., the corner of a building), they are given by the expression:

$$X_i - X_j = 0; \;\; Y_i - Y_j = 0. \quad (24)$$

The points *i* and *j* belonging to the same horizontal plane are given by the expression:

$$Z_i - Z_j = 0. \quad (25)$$

The above equations are introduced into the general system of collinearity equations traditionally used for least squares processing. As a result of solving the general system of equations, the equalized values of the external orientation elements of the images and the coordinates of the control points of the structures are found.

In the normal case of shooting, the accuracy of determining the coordinates of points of building structures using a stereopair is pre-calculated using the formulas (26).

$$\begin{aligned} m_X &= \frac{Y}{f} m_x, \\ m_Y &= \frac{Y}{b} m_p, \end{aligned} \quad (26)$$

$$m_Z = \frac{Y}{f} m_y,$$

where m_x, m_y ,m_p are the mean square errors of measurement of coordinates and longitudinal parallaxes of image points; Y is the distance to the survey object (value of the Y coordinate in the base coordinate system); b (the basis of photographing at the scale of the image) which is calculated by the formula:

$$b = \frac{l_x \left(100\% - P\right)}{100\%}. \tag{27}$$

L_x is the frame size along the x-axis, and P is the longitudinal overlap of stereo pair images, expressed in %.

Obviously, routinely performing such calculations in the field is challenging for surveyors. Thus for practical work it is necessary to make use of the currently existing numerous scientific and commercial software products for processing ground photographs, which allows one to calculate the spatial coordinates of an object with a high degree of reliability under almost any conditions.

The use of modern software products for processing ground photographs transforms a computer monitor into a high-accuracy survey tool and addresses the problems that prevent surveyors from utilizing digital cameras in their work.

Conclusions. Photogrammetric methods for controlling deformations of structures have a few of advantages over geodetic ones [6, 12, 19]. Hence by means of the photogrammetric methods, a large number of construction points (including those in dangerous and hard-to-reach places) are recorded at one physical moment. This makes it possible to assess their mutual static and dynamic deformation, the presence of vibrations and other rapid processes, and simultaneously along all three axes of coordinates. The resulting images are reliable documentary evidence of the presence and magnitude of the recorded deformations. They make it possible at any time to conduct a second independent examination of the measurements which can be performed even several years after photographing the subject.

Photogrammetric methods make it possible to conduct measurements in the conditions of operating enterprises when vibration interference interferes with accurate geodetic measurements.

The suggested control methods enable the use of conventional digital cameras as a practical geodetic measuring instrument, which will cause an increase in labor productivity, and in some cases, that in the accuracy of work at construction sites.

For greater reliability it is recommended that complex monitoring of deformations is performed using various visual and instrumental methods with photographic recording of all detected changes and supplementing them with modern research methods — GPR and laser scanning, and ultrasonic and thermal imaging studies are eemployed to evaluate the damage zone of building structures.

All the control methods listed in the article were developed and tested on the buildings and structures of the VAST (Voronezh nuclear heat supply station), which was suspended in 1993 — the buildings of the chemical water treatment plant and the water cooling system of the SVO, reactor departments No. 1 RD-1 and No. 2 RD-2.

References

1. Ageeva S. T., Novikova N. S., Netrebina Yu. S. Ispol'zovanie geodezicheskikh metodov pri issledovanii deformatsii zdanii i sooruzhenii [The use of geodetic methods in the study of deformations of buildings and structures]. *Student i nauka*, 2018, no. 1, pp. 48—53.

2. Bryn' M. Ya., Tolstov E. G., Nikitichin A. A., Reznik B., Yashchenko A. I., Evstaf'ev O. V., Kuchumov V. A. Geodezicheskii monitoring deformatsii vantovykh mostov na osnove sputnikovykh tekhnologii [Geodetic monitoring of cable-stayed bridge deformations based on satellite technologies]. *Izvestiya peterburgskogo universiteta putei soobshcheniya*, 2009, no. 2, pp. 120—128.

3. Voronov A. A., Popov B. A. Kompleksnyi geotekhnicheskii monitoring zdanii i sooruzhenii Voronezhskoi atomnoi stantsii teplosnabzheniya (VAST) [Integrated geotechnical monitoring of buildings and structures of the Voronezh Nuclear Power Plant of Heat Supply (VAST)]. *Student i nauka*, 2018, no. 4 (7).

4. Epin V. V., Tsvetkov R. V., Shardakov I. N. Deformatsionnyi monitoring fundamentov zdanii metodom gidrostaticheskogo nivelirovaniya [Deformation monitoring of building foundations by hydrostatic leveling]. *Inzhenerno-stroitel'nyi zhurnal*, 2015, no. 3, pp. 21.

5. Zaitsev A. K., Marfenko S. V., Mikhelev D. Sh. e. a. *Geodezicheskie metody issledovaniya deformatsii sooruzhenii* [Geodesic methods for studying deformations of structures]. Moscow, Nedra Publ., 1991. 272 p.

6. Malyuchek T., Fedorova I. Primenenie fotogrammetricheskikh izmeritel'nykh sistem V-STARS v promyshlennosti [Application of V-STARS photogrammetric measuring systems in industry]. *SAPR i grafika*, 2014, no. 10 (216), pp. 98—101.

7. Mel'kumov V. N., Tkachenko A. N., Kazakov D. A., Khakhulina N. B. Perspektivy primeneniya geodezicheskikh metodov nablyudeniya za deformatsiyami pnevmaticheskikh opalubok [Prospects for the application of geodetic methods for monitoring the deformations of pneumatic formwork]. *Nauchnyi vestnik Voronezhskogo gosudarstvennogo arkhitekturno-stroitel'nogo universiteta. Stroitel'stvo i arkhitektura*, 2015, no. 1 (37), pp. 51—58.

8. Nikonov A. V. Osobennosti primeneniya sovremennykh geodezicheskikh priborov pri nablyudenii za osadkami i deformatsiyami zdanii i sooruzhenii ob"ektov energetiki [Features of the use of modern geodetic instruments in the observation of precipitation and deformations of buildings and structures of energy facilities]. *Vestnik SGGA*, 2013, no. 4, pp. 12—18.

9. Fedoseev Yu. E., Egorchenko E. A. Trebovaniya k geodezicheskoi informatsii pri monitoringe deformatsionnykh protsessov mostovykh sooruzhenii [Requirements for geodetic information when monitoring

the deformation processes of bridge structures]. *Inzhenernye izyskaniya*, 2010, vol. December, pp. 50—57.

10. Shekhovtsov G. A., Shekhovtsova R. P. *Sovremennye geodezicheskie metody opredeleniya deformatsii inzhenernykh sooruzhenii* [Modern geodetic methods for determining deformations of engineering structures]. Nizhny Novgorod, NNGASU Publ., 2009. 156 p.

11. Yambaev Kh. K., Krylov V. I. O vozmozhnosti ispol'zovaniya sputnikovykh GPS/GLONASS izmerenii dlya kontrolya vertikal'nosti pri vozvedenii vysotnykh sooruzhenii [About the possibility of using satellite GPS / GLONASS measurements to control verticality during the construction of high-rise structures]. *Izvestiya vuzov. Geodeziya i aerofotos"emka*, 2009, vol. 4, p. 3640.

12. Yashchenko A. I., Burtsev A. V., Dorofeev A. A. Avtomatizirovannyi distantsionnyi monitoring istoricheskogo pamyatnika arkhitektury zdaniya «Srednie torgovye ryady», Krasnaya ploshchad', dom 5 [Automated remote monitoring of the historical architectural monument of the building "Sredniye shopping malls", Red Square, house 5]. *Zhurnal Interekspo GeoSibir'*, 2011, no. 2, vol. 1, 8 p.

13. Kopáčik A., Kyrinovič P., Lipták I., Erdély J. Automated Monitoring of the Danube Bridge Apollo in Bratislava, TS01E — Deformation Monitoring. FIG Working Week 2011 Bridging the Gap between Cultures Marrakech, Morocco, 18—22 May 2011.

14. Bihter E. Evaluation of High-Precision Sensors in Structural Monitoring. Sensors. 2010 №10, p. 10803—10827.

15. Yigit O. C., Inal C., Yetkin M. Monitoring of tall building's dynamic behavior using precision inclination sensors, 13th FIG Symposium on Deformation Measurement and Analysis, 14th IAG Symposium on Geodesy for Geotechnical and Structural Engineering. LNEC. Lisbon, 2008, may 12—15.

16. Cranenbroeck J., Hayes D., Oh S. H., Haider M. Core Wall Control Survey — The State of Art. 7th FIG Regional Conference Spatial Data Serving People, Land Governance and the Environment — Building the Capacity Hanoi, Vietnam, 19—22 October 2009.

17. Cranenbroeck J. V. State of the art in structural geodetic monitoring solutions for Hydropower dams. Interekspo Geo-Sibir', 2012.

18. Groten E., Mathes A., Uzel T. Dam monitoring by continuous GPS observations. Istanbul-94. Ist. Int. Symp. Deform. Turkey, Istanbul, Sept. 5—9, 1994. Abstr. Istanbul, 1994, p. 51.

19. Willfried S. Moderne Messverfahren in der Ingenieurgeodasie und ihr praktischer Einsatz. Flachenmanag. Und Bodenordn, 2002, no. 2, pp. 87—97.

20. Yanhua M., Lixin L., Hong Z. Automatic monitoring system concerning extra-highrise building oscillating based on measurement robot. Proceedings of the 2010 IEEE International Conference on Robotics and Biomimetrics. December 14—18, 2010, Tianjin, China. pp. 662—666.