Studies of vertical position of building walls via surveying method

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Abstract. It is impossible to get a truthful overview of the strain-stress state of any object using the methods recommended by the current regulatory documents to determine the roll of buildings and structures. This paper implements the proposed method of determining the set of roll values by vertical sections of the object. Such a method allows obtaining a detailed picture of deformations, on the basis of which it is possible to develop a qualitative project to restore its design geometry. The paper presents the implementation of methods for determining the complex of values of building rolls with both classical and hinged ventilated facades. The rolls were determined according to 17 vertical sections (9 measurement cycles in total) for a building with a classic facade and 53 vertical sections (53 measurement cycles in total) for a building with a hinged ventilated facade. The results are presented in graphical and tabular form.

1. Introduction

The methods of studying building deformations recommended by the current regulatory instruments require further improvement. Thus, it is recommended to use generalized roll values to determine deformations of buildings and structures in regulatory documents, which cannot sufficiently reflect the real picture of deformed state of buildings and structures [1–6]. Based on such results, it is not possible to make a viable project to restore its design geometry.

In the proposed method, a much larger number of roll values is determined – with a certain pitch, by vertical sections of an object, which characterizes the deformed state of the building in more detail. This method makes it possible to detect stress zones caused by deformations of engineering structures, which is necessary to restore the spatial geometry of the building without additional deformations and faults [7–11].

2. Methods and materials

Roll measurement was performed according to the following procedure. The device on the tripod was installed at a distance approximately equal to the height of the building under control. The coordinate system of the electronic total station was oriented parallel to the controlled plane (building wall). Then, in a single coordinate system, the device coordinated the points under study located in characteristic places of the building. The measurement results were automatically recorded by an electronic total station in the selected tool file. This file was translated to a computer after the
measurements were made. After that, it was imported into the Credo_Dat program intended for camera processing of field engineering and geodetic measurements. In this program, the polar coordinate system of the electronic total station was converted into a rectangular Cartesian coordinate system. Then the resulting 3D point coordinates were exported to the *.dxf (AutoCAD) format. The resulting file was then opened in AutoCAD, where drawing, measurement and analysis of the basic geometry of the building was performed.

The rolls of the structure can be expressed in relative and absolute measures. Besides, there are private \( q_x, q_y \) (for some coordinate plane) and absolute \( Q \) (full roll) for both individual elements and the structure as a whole.

In determining the rolls of the studied building, the method of coordination was used. This method defines the rectangular coordinates of the top \((x_v, y_v, z_v)\) and bottom point \((x_w, y_w, z_w)\) of the construction structure in various ways. It is more rational to implement this method using a modern electronic total station (Figure 1).

![Figure 1. Diagram of roll determination via coordination method](image)

The electronic total station measures a horizontal angle \( \alpha \), a vertical angle \( \nu \) and an inclined distance \( s \) (Figure 1). The following working formulas are used to convert the polar coordinate system to a rectangular Cartesian coordinate system:

\[
h = s \cdot \sin \nu; \quad x = s \cdot \cos \nu \cdot \cos \alpha; \quad y = s \cdot \cos \nu \cdot \sin \alpha.
\]

Private rolls were determined by the following formulas:

\[
q_x = x_1 - x_2; \quad q_y = y_1 - y_2.
\]

The processing of field materials when defining the structure rolls includes the calculation of absolute (complete) roll by the following formula:

\[
Q = \sqrt{q_x^2 + q_y^2},
\]

where \( q_x \) and \( q_y \) – private rolls along \( X \) and \( Y \), respectively.
3. Results

Let us analyze the results of defining the roll complex for the building with classic facade. Figure 1 shows the layout of controlled sections and stations of the device relative to the object under study. The geometry of the building was controlled via 5 stations.

In accordance with Section 5, GOST 24846-81 (Soils. Measurement methods of base deformations of buildings and structures), the limiting errors of roll measurement depending on height $H$ should not exceed $0.0001 \cdot H$ for civil buildings and structures. In our case (at $H = 19$ m) the limiting error of roll measurement makes $1.9$ mm. This measurement accuracy is ensured by the device used (*Trimble 3602 DR* electronic total station).

![Diagram of device standing stations relative to monitored points located on the studied building]

The roll not exceeding $0.005 \cdot H$ is possible. Therefore, if the height is $H = 19$ m, the permissible roll of the building is 95 mm.

Table 1 shows the results of building vertical monitoring performed during different observation periods.
Rule of roll signs. The rolls directed towards the increase in the size of a construction (from the building) have the sign (+), and the rolls directed towards the reduction of the size (inside the building) have the sign (−).

Table 1. Control of vertical position of the building

| Date       | 02.04.2005 | 28.07.2005 | 05.03.2009 | 04.02.2017 | 05.05.2017 | 02.11.2017 | 04.02.2018 | 03.03.2018 |
|------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Frame No.  | q_x         | q_y         | q_x         | q_y         | q_x         | q_y         | q_x         | q_y         |
| 1          | +60         | −101        | −40         | −15         | +46         | −88         | +12         | −89         |
| 2          | +38         | 0           | −66         | +50         | −43         | +40         | −47         | +41         |
| 3          | −−           | −−           | +51         | +49         | −+7         | +37         | +2          | +37         |
| 4          | −−           | −−           | +39         | +42         | −+4         | +44         | −+5         | +50         |
| 5          | −−           | −−           | +27         | +53         | −+5         | +55         | −+6         | +58         |
| 6          | −−           | −−           | +56         | +66         | −+7         | +70         | −+7         | +71         |
| 7          | −45         | +42         | −−           | −−           | +61         | −46         | +57         | −48         |
| 8          | −97         | +26         | −66         | +50         | −43         | +40         | −47         | +41         |
| 9          | +20         | −69         | +70         | −20         | +72         | −16         | +66         | −15         |
| 10         | −38         | +28         | +20         | +98         | −35         | +48         | −46         | −24         |
| 11         | −67         | −55         | −35         | −79         | −44         | −76         | −69         | −71         |
| 12         | +40         | +80         | −45         | +69         | +29         | +57         | +31         | +56         |
| 13         | −−           | −−           | +63         | −+6         | +62         | −+6         | +59         | −+6         |
| 14         | −94         | +60         | −36         | +36         | −78         | +38         | −82         | −46         |
| 15         | +83         | −34         | −46         | −27         | +59         | −35         | +45         | −37         |
| 16         | 0           | −39         | +52         | −26         | +2          | −18         | +3          | −27         |
| 17         | +11         | −38         | +40         | −30         | +6          | −28         | +12         | −34         |

Figure 3 shows the location and numbering of vertical control sections.

Then, let us analyze the results of defining the roll complex for the building with a hinged ventilated facade. As mentioned above in accordance with Section 5, GOST 24846-81 (Soils. Measurement methods of base deformations of buildings and structures), the limiting errors of roll measurement depending on height H should not exceed $0.0001 \cdot H$ for civil buildings and structures. In our case (at $H = 19$ m) the limiting error of roll measurement makes 2 mm. This measurement accuracy is ensured by the above mentioned device (GTS-102N electronic total station).

The roll size which is not exceeding value $0.005 \cdot H$ is permissible (Annex 3). The height of the building under study is 19 m. Therefore, the permissible roll makes 95 mm.

Next, let us analyze the results of defining the roll complex for the building with a classic facade. Due to the fact that the building is covered on all sides with lining, it was decided to control the verticality by the middle of the frames (windows) of the building. Figure 2 shows the diagram of controlled points and standing stations of the device relative to the studied object. Figures 3, 4 and 5 show the results of the window verticality control.
4. Conclusion

The analysis of results on defining the complex of rolls of the building with a classic facade showed the following:

1. No dynamics of verticality change of the main building structures were revealed. These values are within the measurement error range.
2. We see from the verticality control diagram that the building has different-directional rolls. This characterizes the significant accumulated deformation and disruption of the integrity of the internal geometry of the object under study.

3. Maximum wall rolls are fixed on the elevation facing yard of the building.

The analysis of results on defining the complex of rolls of the building with a ventilated facade showed the following:

1. During the period of the studies the recorded vertical displacements of sedimentary grades are within the limits of errors of performed measurements.

2. During the period of the studies the recorded changes of the building roll are within the limits of errors of performed measurements.

The dynamics of deformation of the building is not fixed.

It is recommended to continue observations of deformation dynamics of the studied building.

The measurement results can be used for measures to restore operational reliability of the studied buildings.

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