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DETERMINATION OF MALL BUILDING VERTICAL DISPLACEMENTS BY SEDIMENTARY MARKS

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Abstract. The purpose of this paper is to determine the optimal method of researching the vertical displacements of buildings and stability of the marks, on the basis of which it is possible to make a conclusion about the subsidence of the researched building. Methodology. The main task of geodetic observations for buildings monitoring is to identify changes in the spatial position of load-bearing structures (vertical and horizontal displacements) to assess the risk of structures destruction, dismantling unstable structures, forecasting accidents. In this paper we offered to carry out monitoring by a method of high – precision geometrical leveling on the established geodetic marks, according to one scheme with constant points of devices installation. For testing this method 13 cycles of II class leveling were conducted to determine the vertical displacements of sedimentary marks of the "Shuvar" mall building. To detailed determination of the building deformation, namely its sediment on two floors, we laid 70 marks in the floor on the first floor and 41 marks on the second floor. Stainless steel anchors were used as marks. Findings. According to the results of observations of the laid sedimentary marks we determined their conditional heights. The difference of determined heights of the same marks for a certain period of time allows to determine the vertical displacements. The results of measurements were equilibrated by the nodal point method, and the leveling line was closed on each floor, so the equilibrations were performed separately for each floor. As a result we obtained the heights of sedimentary marks and the mean square errors of their determination. We constructed schedule of heights change of the chosen marks of the first floor within 13 cycles andcarried out the analysis of the reasons of these changes. Practical implications and originality. Observations of landslides, subsidences and deformations of the building have great importance for determining the strength and stability of the building to prevent its destruction or give signal in a timely manner of an emergency, which can become vital. In this paper method for monitoring the vertical displacements of buildings is proposed and tested. The obtained results suggest that proposed method of observations can be recommended to determine the vertical displacements of such buildings and complexes.

Keywords: building deformation, marks, height, geodetic monitoring, vertical displacements, method of monitoring.

Introduction

Due to the constructive features, natural conditions and human activities buildings in general and their separate elements receive different types of deformations. In geodetic practice it is accepted to consider deformation as change of positions of one object concerning some other object. Observations of landslides, subsidences and deformations of the building have great importance for determining the strength and stability of the building to prevent its destruction or give signal in a timely manner of an emergency, which can become vital. The main task of geodetic observations for buildings monitoring is to identify changes in the spatial position of load-bearing structures for the timely implementation of measures to eliminate undesirable processes (Ratushnjak et al., 2014; Ghalinsjkyj et al., 2010; Kubrak et al., 2021).

Uneven subsidence is the most dangerous for the building. They occur due to uneven compression of the soil under the stone prism, causing sags, skews, torsions and cracks. The general causes of sediments are due to the

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peculiarities of engineering-geological and hydrogeological conditions and physical and mechanical properties of soils.

During monitoring of building's deformations, measuring network is mostly used, which consists of the following geodetic points: benchmark – geodetic point that fixes the point of the leveling network (the height position of this point is almost unchanged during observations of deformations); mark – a rigidly fixed point on the building, which changes its height and planned position due to deformation of the building; reference point – practically motionless point in the horizontal plane, relative to which the displacements of building are determined (Ishutina, 2015; Isaev et al., 2013).

Monitoring of building subsidence is always relevant. It makes it possible to determine the condition of the building and prevent accidents, destruction and generally ensure human life.

1. Purpose

The purpose of this paper is to determine the optimal method of researching the vertical displacements of buildings and stability of the marks, on the basis of which it is possible to make a conclusion about the subsidence of the researched building, and to test this method.

2. Methodology

In our opinion, the most effective method of observing the deformations of the building is monitoring by the method of high-precision geometric leveling on the established geodetic marks, according to one scheme with constant points of devices installation (Kubrak et al., 2021). Approbation of this technique was carried out on the example of the "Shuvar" mall building (Lviv).

According to the map of ecological state of the geological environment (Figure 1), the area where the object of study is located belongs to the unfavorable zone, which includes areas of medium ecological risk of air, soil and water pollution by heavy metals and other chemicals.

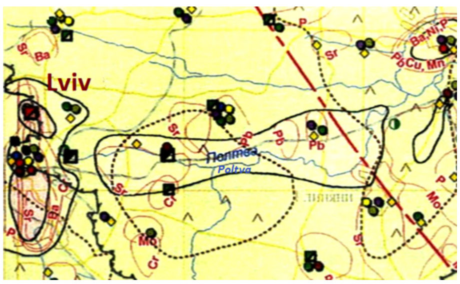
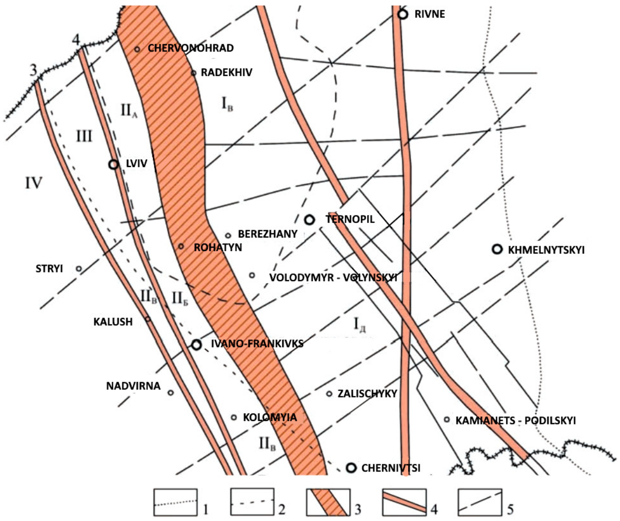


Figure 1. Schematic map of ecological state of geological environment (source: Gherasimov et al., 2004)

Tectonically, the region is located on the border of the Eastern European (ancient) and Western European (young) platforms, the boundary between which runs along the Novovolynsk and Radekhiv-Rohatyn-Monastyrsky faults, which are part of the trans-European suture zone (Teisseira-Thornquist zone). The modern tectonic structure of the region has a block character. Some blocks are limited by zones of deep faults, the main of which have north-eastern and north-western directions (Figure 2). The territory of Lviv is actually located on the edge of the Lviv Paleozoic Depression in the area of the Rava-Rusky deep fault (marked 4-4 in Figure 2). Such tectonic loccation can cause horizontal and vertical tectonic movements and landslides. It should also be noted that in the territories of industrial and urban agglomerations, which are the territories of large cities, the karst process is intensified due to man-made factors (Informacijnyj shhorichnyk, 2013, 2020; Gherasimov et al., 2004).



Note: 1 – the boundary of the Lviv Paleozoic depression; 2 – the boundary of the Pre-Carpathian Depression; 3 – Novovolynsk and Radekhiv-Rohatyn-Monastyry faults (Teisseira-Thornquist zone); 4 – the main faults of the north-western direction (3-3 – Gorodotsko-Kapusky; 4-4 – Rava-Rusky), 5 – the main faults of the north-eastern and sublatitudinal direction (Krupsjkyj, 2014).

Figure 2. Tectonic zoning of the studied region (source: Krupsjkyj, 2014)

In addition, the territory of Lviv belongs to the area of influence of the Vrancea seismic zone, which can cause earthquakes for this area with a maximum magnitude of 5–6.

Given the above studies of the area characteristics, it is very important to study in detail the area under construction and further geodetic support and monitoring of already constructed structures, namely observations of subsidence and deformation of structures (Ratushnjak et al., 2014).

In order to determine the vertical displacements of sedimentary marks of the "Shuvar" mall building, we carried out 13 cycles of II class leveling. The works have been performed since March 2009:

1 cycle – 16.03-26.03.09	8 cycle – 14.10-30.10.10
2 cycle – 27.03-06.04.09	9 cycle – 15.06-30.06.11
3 cycle – 07.04-16.04.09	10 cycle – 01.10-30.10.12
4 cycle – 04.05-14.05.09	11 cycle – 01.11-30.11.13

5 cycle – 15.05-31.05.09 12 cycle – 11.2017
6 cycle – 12.10-20.10.09 13 cycle – 11.2018
7 cycle – 11.05-23.05.10

To determine the vertical displacements of the object under study we laid three wall benchmarks before the observations: Rp1 (directorate building of "Shuvar" mall), Rp2 (nine-storey building on the right side of the entrance to the directorate) and Rp2 (column of a twelve-story building on the left side of the entrance to the directorate) (Figure 3). All benchmarks are laid in buildings that have different foundations and are operated for a long time, which allows to control the stability of their height position with high accuracy.

Figure 3. Location of wall benchmarks

To perform a detailed determination of the building deformation, namely its sediment on two floors, we laid in the floor on the first floor 70 marks, and on the second floor 41 marks. Stamp numbering is indicated by a three-digit number. For the first floor the first digit 1 + mark number (for example 101), for the second floor the first digit 2 + mark number (for example 201). The system of heights is accepted conditional. Rp3 was chosen as the original benchmark, for which the height H = 100.0000 mm was taken. In all cycles to obtain vertical displacements of the building for the initial mark was taken sedimentary mark No. 106, the height of which was determined each time from Rp3 using double leveling. The heights of the other marks were obtained in relation to it. The results of geometric leveling were equilibrated by the nodal point method, and the leveling lines was closed on each floor, so the equilibrating was performed separately for each floor. As a result, the heights of sedimentary marks and the root mean square errors of their determination are obtained.

3. Findings

The heights of part of the sedimentary marks, laid on the first floor of the "Shuvar" mall, according to the 1st–6th leveling cycles and their root mean square errors are given in Table 1. For example, we chose marks that are randomly placed throughout the floor and whose heights differ by a few millimeters.

For example Table 2 shows the heights of the sedimentary marks, laid on the first floor of the "Shuvar" mall, according to the 7–11th leveling cycles and their root mean square errors.

The schedule of heights change of the chosen marks of the first floor within 11 cycles is constructed (Figure 4). As can we seen from Figure 4, the heights of marks from 1 to 9 cycles were almost unchanged, except marks 161 and 162, whose heights gradually increased from 6 to 8 cycles,

Table 1. Heights of sedimentary marks, laid on the first floor of the "Shuvar" mall, and their standard squares errors (1–6 cycles)

No.	Heights and root mean square errors in mm.											
	1 cycle		2 cycle		3 cycle		4 cycle		5 cycle		6 cycle	
	H	m_h	H	m_h	H	m_h	H	m_h	H	m_h	H	m_h
1	2	3	4	5	6	7	8	9	10	11	12	13
102	101 453.8	0.1	101 453.6	0.2	101 453.4	0.1	101 453.6	0.1	101 453.5	0.1	101 453.0	0.1
104	101 455.4	0.1	101 455.3	0.2	101 455.3	0.1	101 455.2	0.1	101 455.2	0.1	101 454.8	0.1
114	101 460.7	0.0	101 460.7	0.1	101 460.5	0.0	101 460.5	0.0	101 460.4	0.0	101 460.4	0.0
116	101 459.5	0.0	101 459.3	0.1	101 459.2	0.0	101 459.3	0.1	101 459.0	0.1	101 458.9	0.1
117	101 455.7	0.1	101 455.6	0.1	101 455.5	0.1	101 455.3	0.1	101 455.3	0.1	101 454.8	0.1
124	101 455.2	0.1	101 455.1	0.1	101 454.8	0.1	101 454.6	0.1	101 454.7	0.1	101 454.3	0.1
125	101 456.8	0.1	101 456.6	0.1	101 456.5	0.1	101 456.3	0.1	101 456.3	0.1	101 456.0	0.1
138	101 465.0	0.1	101 464.9	0.1	101 464.8	0.1	101 464.8	0.1	101 464.6	0.1	101 464.6	0.1
147	101 452.1	0.1	101 451.9	0.2	101 451.9	0.1	101 451.4	0.1	101 451.4	0.1	101 451.2	0.1
161	101 449.6	0.1	101 449.5	0.1	101 449.5	0.1	101 449.4	0.1	101 449.5	0.1	101 449.5	0.1
162	101 442.7	0.1	101 442.5	0.2	101 442.5	0.1	101 442.3	0.1	101 442.5	0.1	101 442.5	0.1
195	101 448.1	0.1	101 448.4	0.1	101 448.3	0.1	101 448.1	0.1	101 448.4	0.1	101 448.2	0.1
199	101 457.7	0.1	101 457.4	0.1	101 457.5	0.1	101 457.7	0.1	101 457.5	0.1	101 457.4	0.1

Table 2. Heights of sedimentary marks, laid on the first floor of the "Shuvar" mall, and their standard squares errors (7–11 cycles)

No.	Heights and root mean square errors in mm.									
	7 cycle		8 cycle		9 cycle		10 cycle		11 cycle	
	H	m_h	H	m_h	H	m_h	H	m_h	H	m_h
1	1	2	3	4	5	6	7	8	9	10
102	101 453.3	0.1	101 452.9	0.1	101 452.5	0.1	101 454.0	0.1	101 452.1	0.1
104	101 455.2	0.1	101 455.0	0.1	101 454.5	0.1	101 455.6	0.1	101 454.4	0.1
114	101 460.5	0.0	101 460.7	0.0	101 460.6	0.0	101 460.8	0.1	101 460.5	0.1
116	101 459.0	0.0	101 459.0	0.1	101 459.0	0.1	101 460.2	0.1	101 458.3	0.1
117	101 455.1	0.1	101 455.0	0.1	101 454.5	0.1	101 456.0	0.1	101 454.3	0.1
124	101 454.8	0.1	101 454.6	0.1	101 454.0	0.1	101 455.2	0.1	101 454.1	0.1
125	101 456.0	0.1	101 456.0	0.1	101 455.2	0.1	101 457.6	0.1	101 454.9	0.1
138	101 464.9	0.1	101 465.0	0.1	101 465.3	0.1	101 464.9	0.1	101 464.4	0.1
147	101 451.5	0.1	101 451.4	0.1	101 451.0	0.1	101 452.4	0.1	101 450.9	0.1
161	101 449.6	0.1	101 450.0	0.1	101 449.8	0.1	101 449.0	0.1	101 450.3	0.1
162	101 443.2	0.1	101 443.8	0.1	101 443.4	0.1	101 443.1	0.1	101 444.7	0.1
195	101 448.6	0.1	101 448.7	0.1	101 448.6	0.1	101 449.7	0.1	101 449.2	0.1
199	101 457.7	0.1	101 457.6	0.1	101 458.5	0.1	101 457.4	0.1	101 457.3	0.1

slightly decreased to 10 cycle and increased again from 10 to 11 cycles, but these changes occurred within 2.5 mm. Marks 114, 138 and 199 changed their height up to 1 mm during the whole period, i.e. they are the most stable. All other selected marks up to 9 cycle remained almost unchanged, from 9 to 10 cycles rose (within 2 mm), and from 10 to 11 fell (within 2 mm). That is, in general, all marks, on which regular observations were made, did not experience critical uplift or subsidence.

Table 3 shows, for example, the heights of part of the sedimentary marks, laid on the first floor of the «Shuvar» mall, according to 1, 12 and 13 cycles and calculated their vertical displacements between cycles 13–1 and 13–12, as well as their root mean square errors.

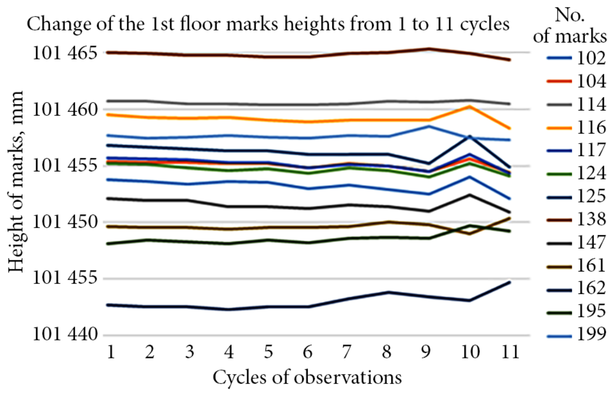


Figure 4. The schedule of heights change of the chosen marks of the first floor during 11 cycles

Table 3. Vertical displacements of sedimentary marks of the first floor of "Shuvar" mall according to the 1st, 12th and 13th cycles

No.	Heights of marks (mm)			Shift and m.s.e. of shifts			
	cycles			The shift between the cycles 13–12 (mm)	m_{13-12} (mm)	The shift between the cycles 13–1 (m)	m_{13-1} (mm)
	1	12	13				
102	101 453.8	101 454.1	101 453.5	–0.6	0.1	–0.3	0.1
116	101 459.5	101 460.2	101 459.5	–0.7	0.1	–0.1	0.1
120	101 454.2	101 454.9	101 454.4	–0.5	0.1	0.1	0.1
123	101 455.8	101 456.4	101 455.8	–0.6	0.1	0.0	0.1
130	101 454.2	101 454.4	101 457.4	3.0	0.1	3.1	0.1
133	101 460.7	101 450.0	101 448.3	–1.7	0.1	–12.4	0.1
144	101 459.3	101 459.9	101 459.3	–0.6	0.1	0.1	0.1
150	101 458.3	101 458.7	101 458.3	–0.4	0.1	0.0	0.1
162	101 442.7	101 437.6	101 438.0	0.4	0.1	–4.7	0.1
166	101 451.7	101 446.8	101 446.8	0.0	0.1	–4.9	0.1

Figure 5 shows a graph of displacements of marks between the 13th and 1st cycles, and the 13th and 12th cycles of observations on the first floor of the building. As we can see from the graph, most marks have been subsidenced. The mark No. 133 subsidenced the most on about 12 mm, the other marks shifted to –5 mm. Marks 107, 120, 122, 125–130 were raised, the highest value was reached by the mark No. 130 up to 3 mm. Between the 13th and 12th cycles, the displacements acquired mainly negative values (subsidence) up to 1 mm, mark No. 133 has the maximum by –1.8 mm, small positive values of displacements (lifting) have marks 130 (+2.5 mm), 159–166 (up to +0.5 mm).

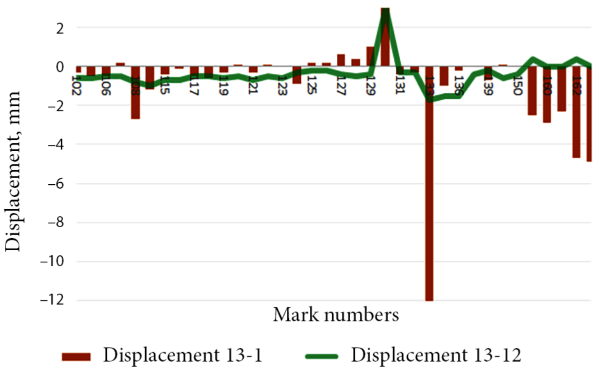


Figure 5. Graph of shift of marks between 13 and 1 cycle, and 13 and 12 cycle of observations on the first floor of the building

Based on the results of the calculated displacements, isolines of vertical displacements of sedimentary marks of the first floor were constructed according to the data of 1–13 cycles (Figure 6). As we can see from this figure, the largest subsidence has the part of the building near the stairwell (western part), partly the central and north-eastern part.

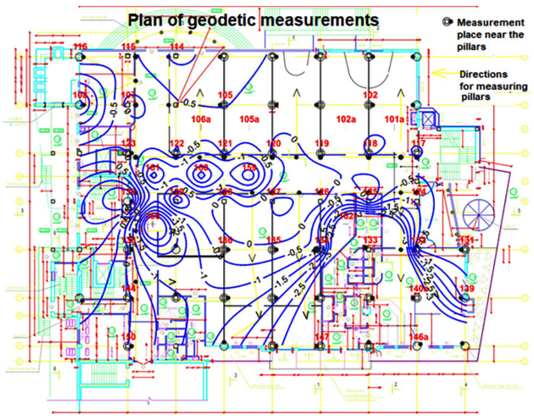


Figure 6. Isolines of vertical displacements of sedimentary marks of the first floor according to 1–13 cycles

In general, the vertical displacements of the building for the entire observation period (9.7 years) are mostly uniform. The average vertical displacement of the building is –1.4 mm, which does not pose any danger to the operation of the building.

4. Practical implications and originality

Observations of landslides, subsidences and deformations of the building have great importance for determining the strength and stability of the building to prevent its destruction or give signal in a timely manner of an emergency, which can become vital. In this paper method for monitoring the vertical displacements of buildings is proposed and tested. The obtained results suggest that proposed method of observations can be recommended to determine the vertical displacements of such buildings and complexes.

Conclusions

The tectonic location of Lviv on the border of the Eastern European and Western European (Hercynian) platform, on the edge of the Lviv Paleozoic trough in the zone of the Rava-Rusky deep fault (Krupsjkyj, 2014) can cause small horizontal and vertical tectonic movements and landslides. And since the territory of Lviv belongs to the influence of the Vrancea seismic zone, which suggests the possibility of seismic events with a magnitude of 5–6, the observation of the stability and deformation of large buildings is extremely important. It should also be noted that in the whole Lviv region, as well as in Lviv, rocks are widespread capable of karstification, and in the territories of large cities the karst process is additionally intensified due to man-caused factors, which is especially dangerous (Gherasimov et al., 2004; Prymushko et al., 2020).

Therefore we believe that the proposed method of monitoring buildings by high-precision geometric leveling on established geodetic marks, according to scheme with constant points of devices installation, which is tested on "Shuvar" mall (Lviv), can be proposed for using on such buildings, as it gives detailed and reliable results, and in comparison with other methods allows to observe the laid marks with lower costs, gives more complete and detailed information about the deformation condition of the building.

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