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GEODETIC MONITORING OF DEFORMATIONS OF THE EARTH'S SURFACE AND THE MAIN GAS PIPELINE IN THE AREA AFFECTED BY MINING OPERATIONS

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Abstract. *The importance of the task of calculating and analyzing the displacements and deformations of the earth's surface for monitoring the state of objects located on the earth's surface within the influence of mining operations is substantiated. Studies have been conducted that indicate that the actual values of earth surface displacements and deformations differ significantly from the calculated values determined by standard methods. Today, when developing measures to protect objects on the earth's surface, a regulatory methodology is used that applies an overload coefficient. However, it does not make it possible to determine the actual range of the variation of subsidence and deformation of the earth's surface.*

The authors of the article substantiate the design of an observation station for geodetic measurements of earth surface displacements and deformations of the main gas pipeline, which is being undermining by the Geroyev Kosmosa mine of DTEK Pavlohradvuhillya.

An observation station was laid and instrumental observations were made using a GNSS receiver from Leica Geosystem.

According to the normative methodology, the expected and calculated subsidence and deformation of the earth's surface within the influence of the 960th longwall were calculated for certain mining and geological conditions. The results obtained by the authors during the natural measurements confirm the variation of subsidence and *deformation along the main sections of the trough. It is proposed to take the obtained results into account when choosing the means of protection of the main gas pipeline.*

Key words: *displacement and deformation of the earth's surface, geodetic monitoring, observation station, GNSS observation, natural measurements, trough.*

Problem statement

The analysis of movements and deformations of the earth's surface and objects located on it remains an urgent task when it is being undermining with by mining operations and is critical to ensuring safety, infrastructure preservation, environmental sustainability, mining efficiency, etc.

Mining operations can cause significant changes in the earth's surface relief and the structure of the earth's strata, which is caused by landslides, subsidence, and displacement of the rocks. Deformation monitoring helps to identify potential hazards in time and take the necessary measures to eliminate them. In turn, deformations of the earth's surface can adversely affect buildings, roads and other infrastructure located in the area affected by mining operations. Regular monitoring of deformations helps to protect this infrastructure and avoid high costs for its repair or reconstruction. From an environmental perspective, continuous monitoring of ground deformations is necessary to identify changes and timely address the impact of mining operations on the local ecosystem, including water resources, soil and vegetation.

Analysis of recent research and publications

To date, the calculation of expected and calculated displacements and deformations of the earth's surface is performed according to the methodology described in the regulatory document [1]. However, even when using this methodology for calculating the deformations of the earth's surface for a long time, deformations and destruction of the objects being undermining still occur. The works of many domestic and foreign authors show the actual results of the impact of earth surface deformations on objects located within mining operations [2-4].

The works of the authors of articles [5-8] present the results of field observations or various modeling studies that indicate the difference between the calculated displacements and deformations of the earth's surface and their actual values. This variation occurs as a result of the influence of various factors on the displacement process (geometric, mining and geological conditions, physical and mechanical properties of rocks, etc.)

Thus, the relevance of observing the deformations of the earth's surface and studying the impact of these deformations on undermining objects remains to this day.

The purpose of the study

This articl presents the results of natural instrumental observations carried out in the mining area of the Geroyev Kosmosa mine of DTEK Pavlogradugol. The object of the study is a high-pressure gas pipeline to Ternivka town on the territory of Verbkivska territorial community of Dnipropetrovska oblast. The geodetic observations were performed to substantiate the rational undermining of the gas pipeline section, which guarantees its safe use for its intended purpose.

Materials and methods of the study

Fig. 1 shows a fragment of an extract from the mining plan of the layer c_9 with the boundary of the zone of influence of the cleaning operations of the 960th longwall, the position of the gas pipeline and the location of the profile line of the observation station.

This area of the earth's surface and the main gas pipeline was previously mined by the mining operations of the layers c_{10} and c_{11} and is currently mined by the 960th longwall of the layer c_9. On the reverse strike side, the longwall is adjacent to the 956th longwall. There are no other working longwalles on the down-fall, up-fall, or down-strike sides.

The main mining and geological characteristics of the 960th longwall of the layer c_9:

- The length of the pole is 1326 m,
- The length of the longwall is 250 m,
- The angle of incidence is 4°,

- The average depth of development is 321 m,

- reservoir layer c_9 - 1.05 m,

- sediment layer c_9 - 160 m,

- coal grade - DG.

The cover of the layer c_9 is predominantly siltstones (50%) and mudstones (35%), less often sandstones (10%) and bushy mudstones (5%).

The mining is carried out with a long pole behind the fall. Full collapse is used as a method of roof control in the longwall.

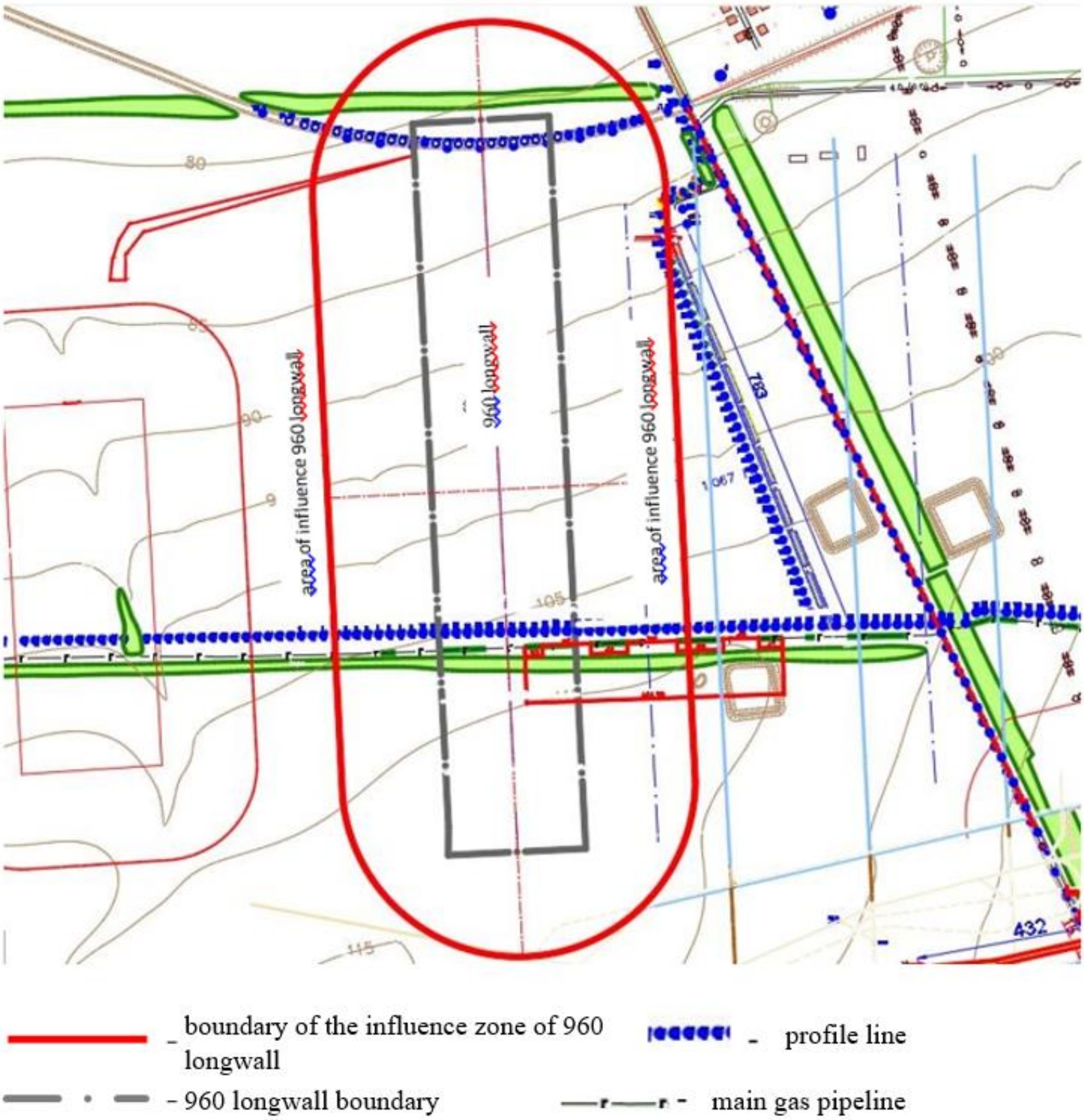

Figure 1. A fragment of a copy from the mining plan of the layer c9

The underground main gas pipeline to Ternivka, Dnipropetrovska oblast, from the Shebelynka-Dnipropetrovsk-Odesa main gas pipeline was commissioned in 1986 and is operated by Zaporizhzhia LP UMG (Dnipropetrovska site). The design of the undermining was developed taking into account the probable tensile-compressive deformations of the earth's surface from $2{,}0\times10^{-3}$ to $5{,}0\times10^{-3}$ in accordance with the mining and geological study.

The main gas pipeline to Ternivka is made of welded pipes with a diameter of 325 mm and a wall thickness of 6 mm made of steel 20, its length is 651 m in the zone of influence of the 960th longwall layer c_9 - between design points 1 and 34.

The main mechanical characteristics of the pipeline are given in the quality certificate: temporary tensile strength of steel 420 MPa, yield strength of steel 245 MPa. The design pressure in the gas pipeline: maximum 55 kgf/cm^2, minimum 31 kgf/cm^2. The depth of the gas pipeline is 0,8 m to the top of the pipe, the backfill soil is hard loam.

The pipeline is protected from soil corrosion by a 0,63 mm thick film and cathodic protection. The gas pipeline was designed as a Category II pipeline with 100% X-ray inspection of all welded joints and using 325×6 mm diameter pipes with a 10% safety margin [9].

Before performing the field instrumental measurements, we calculated the expected earth surface displacements for the above-described undermining conditions. The calculation was performed according to the current methodology [1].

The mining impact zone is determined by the boundary angles on vertical cross-sections and along the strike of the layer. The boundary angles are determined according to [1]. The boundary angles were: $\beta_0 = 65°$; $\gamma_0 = 65°$; $\delta_0 = 65°$, in sediments $\varphi_0 = 45°$. The angles of total displacements were: downthrust $\psi_1 = 55°$; upthrust $\psi_2 = 56{,}2°$; downthrust $\psi_3 = 55°$. The angle of maximum subsidence was $\theta = 86{,}8°$. The maximum subsidence of the earth's surface η_m was 840 mm.

The purpose of instrumental measurements at the observation station is geodetic monitoring of ground deformations at the main gas pipeline laying site with further justification of the means of its protection against damage. The observation station consists of a profile line of soil raps located along the gas pipeline route.

According to [10], the soil raps of the observation station are laid 20 m apart and located at a distance of 15 m from the projection of the gas pipeline axis to the ground surface. The reference raps (Rp I and Rp II) of the observation station were laid outside the influence of mining operations at a distance of 50 and 100 meters. The total length of the profile line along the pipeline route is 860 m, and the number of soil raps is 34. The location scheme of the observation station is shown in Fig. 2.

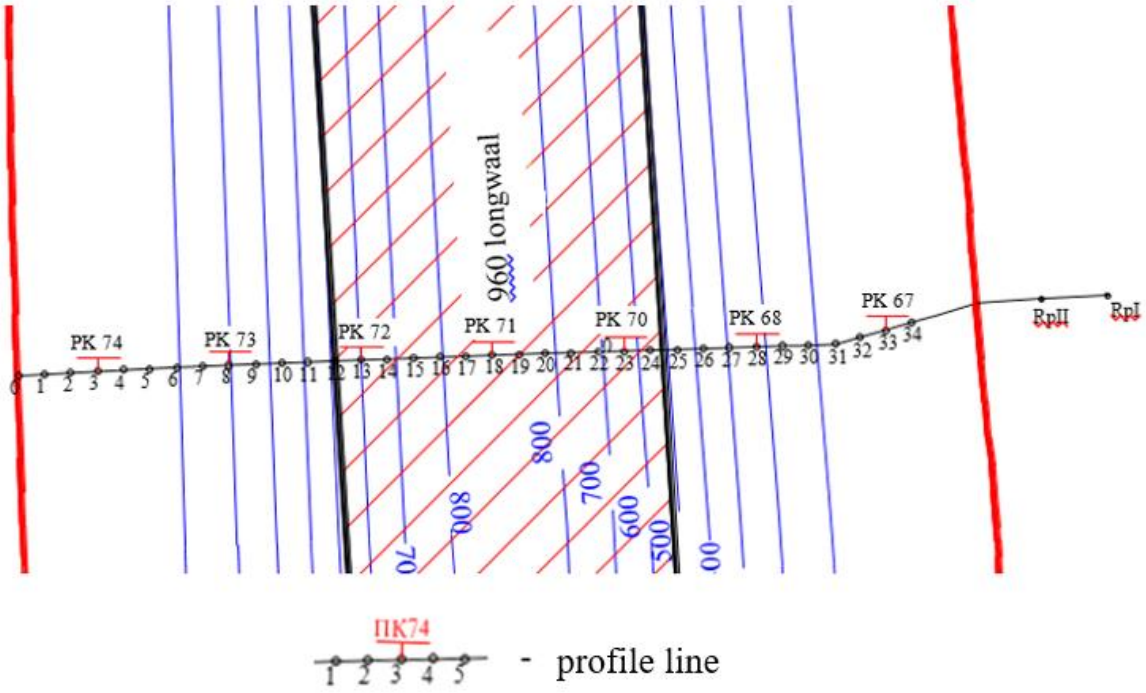

Fig. 2. Scheme of the observation station

The main requirement for the design of the soil raps at the observation station was that they should not be affected by seasonal freezing and heaving soil. The raps were made of metal rods 1,5 m long and 20 mm in diameter. A 1,2 mm diameter and 5-7 mm deep hole was drilled in the upper ends of the raps [10].

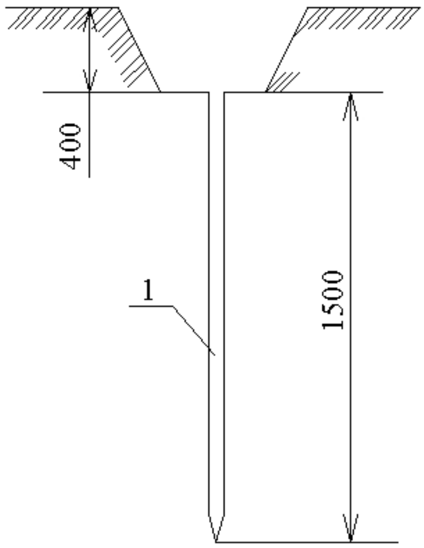

Fig. 3. Construction of the rapper

1 - metal rod

The altitude reference of the observation station's references is carried out according to the class IV leveling method from the original raps located at the industrial site of the Geroyev Kosmosa Mine.

The observation station was installed before the start of the ground movement process caused by the mining operations of the 960th longwall. The beginning of the displacement process from the 960th longwall is taken as the moment when its cleaning face moves away from the cutting face by a distance equal to 47,4 m. The initial position of the raps was determined from two series of observations before the start of earth surface undermining. The gas diversion pipeline is a potentially hazardous object, so the following series of instrumental observations were carried out twice a month in accordance with [10].

In case the actual values of displacements and deformations exceed the permissible values, the results of instrumental observations should be submitted for control to the G. S. Pysarenko Institute of Strength Problems of the National Academy of Sciences of Ukraine LLC [11].

During the instrumental observations, we used a geodetic GNSS receiver from Leica Geosystem, namely the Leica Viva GS08 Plus receiver and the Leica Viva CS10 field controller.

The controller is based on the Windows Embedded Handheld operating system, which allows the use of a wide range of professional software. Support for RTK (Real-Time Kinematic) technology allows obtaining highly accurate results in real time [12].

To confirm the accuracy of the geodetic base, before starting field observations at the object, control measurements were made at the points of the State Geodetic Network of Ukraine, the coordinates of which are known in the selected coordinate system [13].

The accuracy of the work involving the Leica GS08 with the Leica CS10 field controller, in the static mode, is 5 mm + 13 mm (1 mm per 1 km of communication range, fixed for the entire survey) and amounts to 18 mm accuracy of surveying raps and observation points.

Research results and discussion

At each observation point, the X, Y, and H coordinates were obtained twice, at a height of 2,00 m and 1,50 m. Table 1 shows a catalog of average coordinates obtained on one of the observation dates. Similar tables were obtained for each observation date.

1. Catalog of survey coordinates as of July 13, 2023

№ point	**X**	**У**	**H**
Rp1	86665,459	-5241,223	99,881
Rp2	86690,569	-5272,335	100,173
Rp3	86716,36	-5304,675	100,529
Rp4	86727,868	-5319,007	100,854
Rp5	86740,269	-5334,459	100,95
Rp6	86752,912	-5350,103	101,04
Rp7	86765,486	-5365,978	101,125
Rp8	86777,989	-5381,571	101,241
Rp9	86790,515	-5397,277	101,372
Rp10	86802,887	-5412,754	101,522
Rp11	86815,48	-5428,392	101,698

Rp12	86828,068	-5443,964	101,913
Rp13	86840,544	-5459,448	102,081
Rp14	86852,959	-5474,998	102,256
Rp15	86865,495	-5490,627	102,37
Rp16	86877,903	-5506,192	102,539
Rp17	86890,363	-5521,728	102,77
Rp18	86902,818	-5537,355	102,837
Rp19	86915,252	-5552,946	103,036
Rp20	86927,814	-5568,301	103,271
Rp21	86940,231	-5583,993	103,543
Rp22	86952,535	-5599,733	103,867
Rp23	86965,215	-5615,214	104,212
Rp24	86977,577	-5630,838	104,446
Rp25	86990,139	-5646,355	104,783
Rp26	87002,711	-5661,939	104,871
Rp27	87015,088	-5677,675	105,103
Rp28	87027,885	-5693,461	105,34
Rp29	87040,186	-5709,081	105,443
Rp30	87052,734	-5724,725	105,581
Rp31	87065,188	-5740,407	105,862
Rp32	87077,783	-5755,948	106,173
Rp33	87088,376	-5769,115	106,351
Rp34	87100,802	-5784,683	106,369

When developing measures to protect buildings and structures, calculated displacements and deformations are used, which are obtained by multiplying the expected displacements and deformations by overload coefficients [1].

Based on the results of the field measurements, the calculations of the calculated subsidence and deformation of the earth's surface were performed according to the regulatory document [1]. Fig. 4 shows the calculated and actual subsidence of the earth's surface.

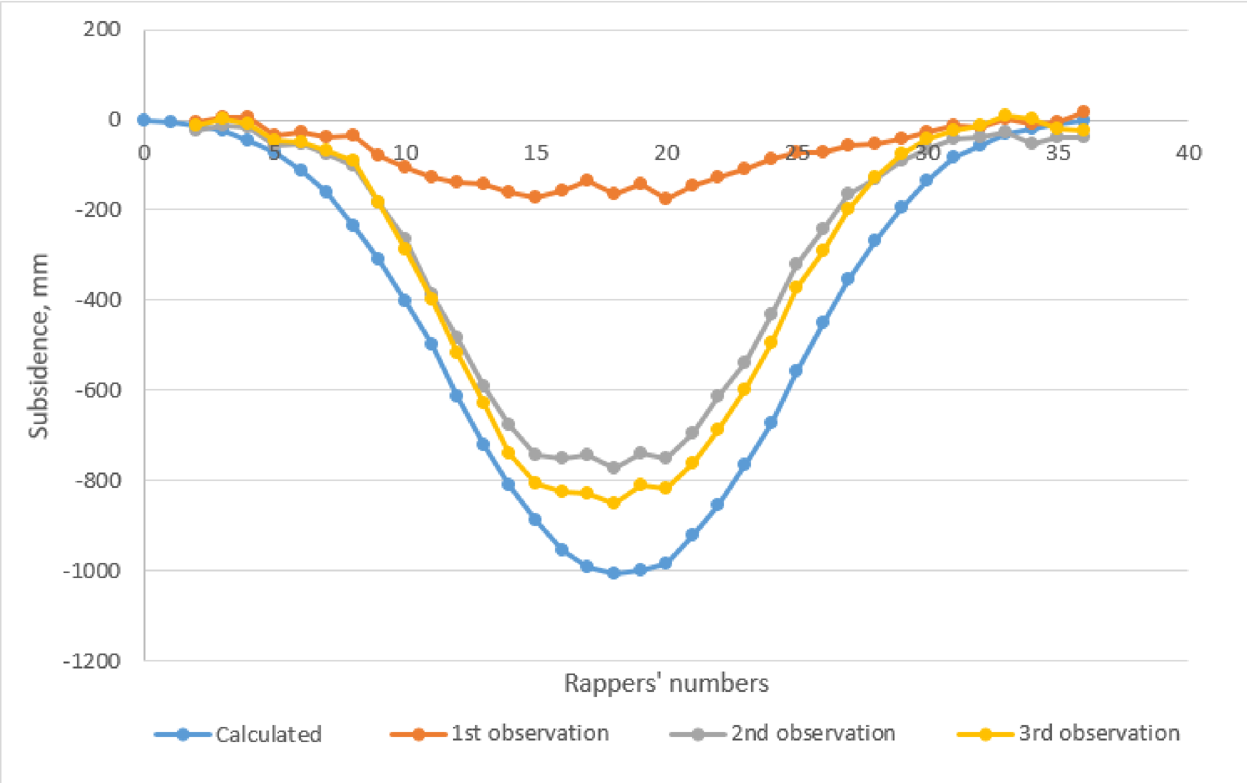

Fig. 4. Graph of land surface subsidence along the profile line

As can be seen from Fig. 4, the subsidence obtained from GNSS observations generally has the same trend as the calculated subsidence. The maximum subsidence is observed at the level of 18 raps (849 mm) and is recorded in the center of the trough. At the same time, the subsidence obtained from field measurements does not exceed the calculated subsidence (1008 mm).

Fig. 5 at shows a graph of the earth's surface tilts along the profile line of the observation station, obtained as a result of processing the data on the subsidence of field measurements and calculated according to the methodology [1].

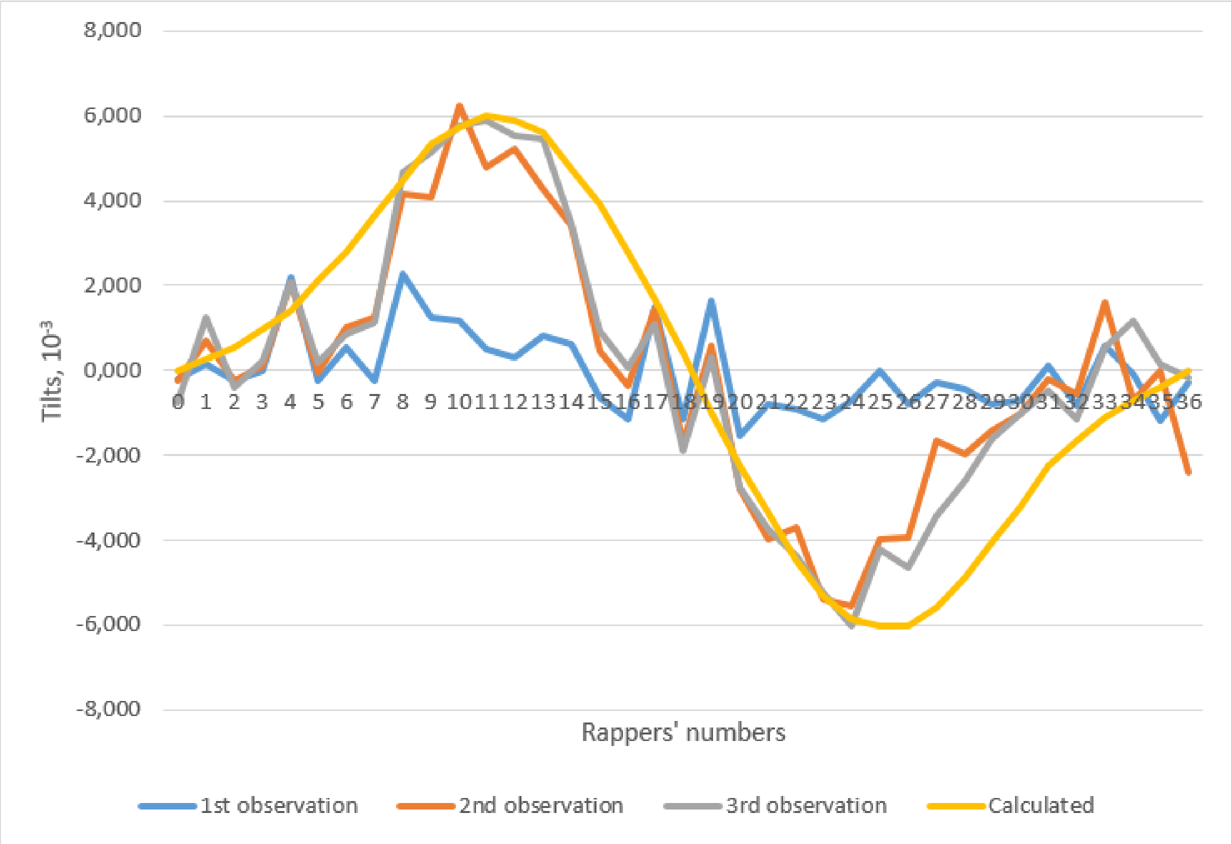

Fig. 5. Graph of tilts along the profile line

Analyzing Fig. 5, we can see that the tilts obtained from the field measurements exceed the calculated values (e.g., at raps 1, 4, 10, 24, and others), and in some cases even have the opposite sign (e.g., raps 2, 5, 19, 33, and others).

Deformations such as curvature and horizontal displacements were not considered, as the most dangerous for gas pipeline communications are horizontal compression and tension deformations.

Fig. 6 shows the graphs of the calculated horizontal deformations obtained according to the current regulatory document [1] and those obtained from the results of field measurements.

Fig. 6 shows that the calculated horizontal deformations of the earth's surface along the gas pipeline route have maximum compression values in the area of rap 18 ($-4{,}7\times10^{-3}$). The maximum tensile values are observed at raps 7 and 29 ($3{,}2\times10^{-3}$).

However, according to the results of field observations, the maximum values of compression are observed at the level of raps 14 and 22, and are $-4{,}7\times10^{-3}$ and $-4{,}6\times10^{-3}$, respectively. At the same time, the maximum tensile values are observed within the limits of raps 9 and 27 ($3,9\times10^{-3}$ and $4,5\times10^{-3}$), which is much higher than the calculated ones.

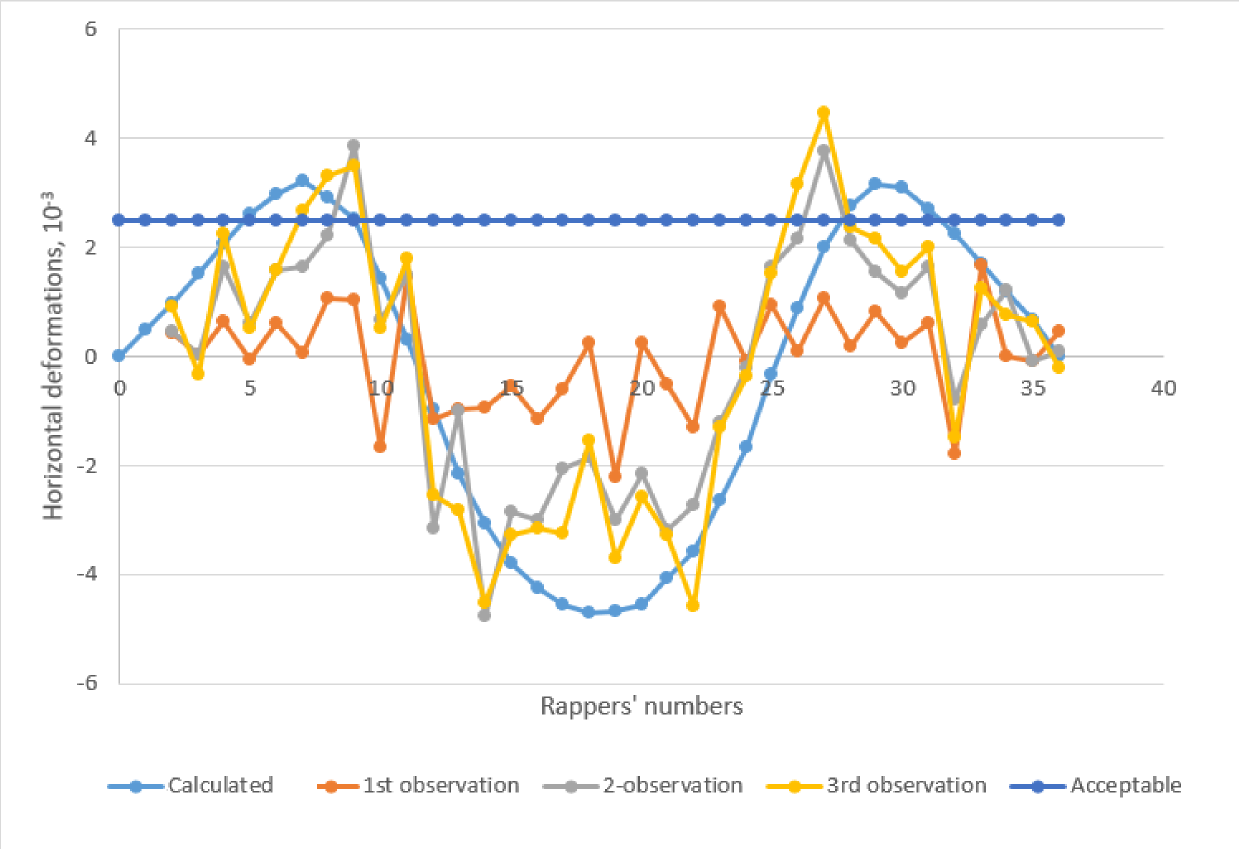

Fig. 6. Graph of horizontal deformations of the earth's surface along the profile line

In addition, some of the raps have the opposite sign of horizontal deformations compared to the calculated values. For example, on the rap 32, the calculated horizontal deformations are $2,24\times10^{-3}$, while the horizontal deformations according to the 3rd observation are $-1,50\times10^{-3}$.

Fig. 6 shows in blue the line of permissible values of horizontal deformations ($2,5\times10^{-3}$) calculated for this gas pipeline, taking into account its characteristics. At the same time, the horizontal deformations along the profile line exceed the permissible values by $0,2\text{-}2,0\times10^{-3}$ in the ranges of raps 5-10 and 26-31, which is 1,8 times higher than the permissible values and is unacceptable for a main gas pipeline.

Conclusions and prospects

Thus, it can be concluded that the regulatory document for calculating displacements and deformations needs to be improved. To date, the use of the overload coefficient is not sufficient to determine the possible variation of displacements and deformations. There is a need to introduce corrections for the variation of physical and mechanical properties of the rock mass, for the relief, for errors in field measurements, etc. The obtained results of field measurements will be further used in the development of measures to protect the main gas pipeline.

References

1. Pravyla pidrobky budivel, sporud ta pryrodnykh obiektiv pry vydobuvanni vuhillia pidzemnym sposobom: HSTU 101.00159226.001-2003. [Chynnyi vid 2003–11–22]. K.: Minpalyvenerho Ukrainy. 2003. 126 (in Ukr.).
2. Kuchyn, O., Bruy, G., Yankin, O. (2023). Modeliuvannia prostorovoho zmishchennia tochok zemnoi poverkhni za rezultatamy heodezychnykh sposterezhen. [Modeling of the spatial displacement of points on the earth's surface based on the results of geodetic observations]. Prostorovyi rozvytok. 3, 122–133.
3. Gordienko, M., Kolesnik, N., Kozlovsky, G., Nazimko, V. (2013). Udoskonalennia metodyky rozrakhunku deformatsii pidrobliuvanykh budivel ta sporud. [Improvement of the methodology for calculating deformations of undermining buildings and structures]. Problemy hirskoho tysku. 22-23, 137-166.
4. Blachowski, J., Cacoń, S., Milczarek, W. (2007). The influence of mining in complicated geological conditions on surface of the ground. International Society for Mine Surveying. XIII International Congress. Budapest.
5. Luo, Y. (2009).Techniques to Investigate Subsidence Events Over Inactive Room-and-Pillar Mines. 28th International Conference on Ground Control in Mining. Morgantown. Available at: http://icgcm.conferenceacademy.com/papers/allpapers.aspx?subdomain=icgcm&MeetingID=420
6. Chris, M. (2002). Rock Mechanics Section NIOSH. 21st International Conference on Ground Control in Mining. Morgantown, USA, 377 pp.
7. Bugayova, N., Nazimko, V. (2008). Osoblyvosti rozpodilu stokhastychnykh vidkhylen osidan zemnoi poverkhni pry yii pidrobtsi odynochnoiu lavoiu. [Features of the

distribution of stochastic deviations of earth surface subsidence when it is undermining by a single longwall]. Problemy hirskoho tysku. 16, 194-237.

8. Kodunov, B.A. (2010). Raspredelenye vertykalnыkh deformatsyi v zone sdvyzhenyia hornыkh porod. [Distribution of vertical deformations in the shear zone of rocks]. Visti Donetskoho hirnychoho instytutu. 2, 11-16.

9. Proiekt pidrobky dilianky mahistralnoho hazoprovodu-vidvedennia vysokoho tysku do m. Ternivka 960 lavoiu plasta s_9 shakhty im. Heroiv kosmosu VSP «Shakhtoupravlinnia imeni heroiv kosmosu» PrAT «DTEK Pavlohradvuhillia». 2021. (in Ukr.).

10. Instruktsiia zi sposterezhen za zsuvom hirskykh porid, zemnoi poverkhni ta sporudamy, shcho pidrobliaiutsia na vuhilnykh i slantsevykh rodovyshchakh. 1989. 96. (in Ukr.).

11. Oryniak, I.V., Borodii, M.V., Bohdan, A.V. (2007). Vykorystannia katehoryzatsii napruzhen i deformatsiinykh kryteriiv pry otsintsi mitsnosti mahistralnykh truboprovodiv. [The use of stress categorization and deformation criteria when assessing the strength of main pipelines]. 4, 6-15.

12. Huang, G., Du, S., Wang, D. (2023). GNSS techniques for real-time monitoring of landslides: a review. Satellite navigation. 4, No. 1, 1–10.

13. Pro zatverdzhennia Instruktsii z topohrafichnoho znimannia u masshtabakh 1:5000, 1:2000, 1:1000 ta 1:500 (HKNTA-2.04-02-98) Dokument z0393-98, potochna redaktsiia. Redaktsiia vid 28.09.1999. Available at: https://zakon.rada.gov.ua/laws/show/z0393-98#Text (in Ukr.).

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ГЕОДЕЗИЧНИЙ МОНІТОРИНГ ДЕФОРМАЦІЙ ЗЕМНОЇ ПОВЕРХНІ ТА МАГІСТРАЛЬНОГО ГАЗОПРОВОДУ В ЗОНІ ВПЛИВУ ГІРНИЧИХ РОБІТ

Анотація. *Обґрунтована важливість задачі розрахунку й аналізу зрушень та деформацій земної поверхні для моніторингу за станом об’єктів,* *розташованих на земній поверхні в межах впливу гірничих робіт. Були проведені дослідження, які вказують на те, що фактичні величини зрушень та деформацій земної поверхні суттєво відрізняються від розрахункових, визначених за стандартними методиками. Сьогодні при розробці заходів захисту об'єктів на земній поверхні використовується нормативна методика, в якій застосовується коефіцієнт перевантаження. Однак, він не дає можливості визначення фактичного діапазону варіації осідань та деформацій земної поверхні.*

Авторами статті обґрунтовано проєкт спостережної станції для геодезичних вимірювань зрушень земної поверхні та деформацій магістрального газопроводу, що підробляється шахтою ім. «Героїв космосу» ПрАТ «ДТЕК ПАВЛОГРАДВУГІЛЛЯ».

Виконано закладання спостережної станції та проведені інструментальні спостереження із використанням ГНСС приймача компанії Leica Geosystem.

За нормативною методикою для певних гірничо-геологічних умов розраховані очікувані й розрахункові осідання та деформації земної поверхні в межах впливу 960-ї лави. Результати, отримані авторами під час виконання натурних вимірювань, підтверджують розкид осідань та деформацій вздовж головних перерізів мульди зрушення. Запропоновано враховувати отримані результати при виборі засобів захисту магістрального газопроводу.

Ключові слова: *зрушення та деформації земної поверхні, геодезичний моніторинг, спостережна станція, ГНСС-спостереження, натурні вимірювання, мульда зрушення.*