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Landslide processes at the objects of the oil and gas complex in the Carpathians

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SUMMARY

Based on the analysis of natural hydrogeological features of the upper part of the section, geometric characteristics of slopes, physical and mechanical properties of soils and bedrock at the objects of the oil and gas complex in the Carpathians, mathematical modeling, it was established that there are no causes for the formation of natural surface landslide processes for the studied territory. Surface landslide processes in the areas where the boreholes are located, associated with the consequences of the construction of the wells and the surface facilities as well as the development of oil and gas fields, are provoked by deep tectonic movements and neotectonic activity of this area.

The main reason for the deformation of the boreholes is discontinuous disturbances of various genesis and rank (thrusts, faults, zones of increased fracturing) and lithologic-stratigraphic boundaries of the Vorotyshcha, Polyanytsia, and Menilite formations.

It was found that the highest intensity of tectonic movements is observed within the Berehovy Nappe, the lower one corresponds to the steep subthrust limbs and areas of deep folds not covered by the thrust, and the lowest ones occur in sloping fold limbs.

Berehovy Nappe is characterized by the greatest intensity of tectonic movements, the steep wings of the subthrust and areas of deep folds not covered by the thrust correspond to the lower, and the lowest are characteristic of the gentle wings of the folds.

It is recommended to carry out the geological and geophysical monitoring (twice a year - spring and autumn) in order to control the possible activation of landslide processes, including the ones caused by the man-made load on the slopes, which lead to the violation of springs, discharge zones and filtration of natural (underground and surface) and technological waters. When choosing the locations of new exploration and production boreholes, it is recommended to conduct a targeted engineering and geological survey of the sites using the developed equipment and methodical complex in order to assess the possibility of the occurrence of sliding processes caused by both the features of the upper part of the section and the deep structure.

Introduction

The Carpathian oil and gas-bearing province is one of the oldest provinces not only in Europe but also in the world, oil production here began in 1771 near the village of Sloboda Rungunska and continues till present (Krupskyi, 2001). The complexity of the geological structure of the Carpathian oil and gas-bearing region, the influence of geodynamic factors, the processes of exploration and development of oil and gas fields lead to technogenic stress on the environment, which causes both near-surface and elastic deformation processes in the geological environment (Kurovets et al., 2018). In order to assess the man-made load on the environment during the exploration and development of the fields in complex geological conditions that cause landslides, we conducted research on the territory of the Bytkiv-Babche oil and gas condensate field located in the Nadvirna district of the Ivano-Frankivsk region (Atlas, 1998). The first mentions of oil production in this area date back to 1860. Initially, oil was extracted with the help of mines (pits-wells), which were mainly located in the Bystrytsia floodplain just below the mouth of the Kozyrka stream, and starting from 1886, oil from the "slab horizon" began to be extracted with the help of impact drilling boreholes. In 1948, the second period in the history of the Pasichna industry began. Borehole 256 opened the vaulted part of the Bytkiv deep fold and in 1951 produced a commercial flow rate from the Menilite formation. In 1958, exploration of the Paleocene gas-condensate accumulation of the Bytkiv deep anticline was started. More than 100 deep boreholes were drilled on the territory of Pasichna to develop the Menilite and Paleocene-Eocene accumulations of the deep structure. Thus, over the entire period of the industry's existence, more than 500 boreholes were drilled, and their average density is approximately 23 boreholes per km2. At the same time, the average density of boreholes within the boundaries of the old production area of the "slab horizon" exceeds 100 boreholes per km2.

Method and/or Theory

According to the results of our earlier research and the analysis of published data (Goshovsky et al., 2004; Rudko et al., 2007; Kuzmenko et al.; 2004, Shamotko, et al., 2002), we have made it possible to develop a rational scheme and methods of complex geological and geophysical studies of landslide processes in the studied territory (Kurovets et al., 2011), which includes the following set of studies:

- analysis of the geomorphological and hydrogeological features of the sedimentary stratum of the upper part of the section, plant cover and man-made load with a purpose of studying the regularities of the structure and processes of their geological development;
- study of mechanical properties and determination of angles of internal friction, indicators of shear resistance, swelling, height of capillary rise of the bedrocks and ground cover;
- carrying out a complex of geophysical studies to determine the dynamics of capacity-filtration processes to identify the most dangerous areas of geoenvironmental degradation;
- development of recommendations for measures to control and prevent landslides.

Results

The work was carried out in several stages. At the first stage, the state of the problem was analyzed, a general geomorphological and hydrogeological analysis of the upper part of the section was carried out, the engineering and geological aspects of rock deformation were studied, taking into account what a methodological and equipment complex of research was formed, which included the technology of conducting research and data processing, methods of studying physical and mechanical properties of soils and chemical composition of waters, methods and equipment of terrestrial geophysical observations. At the second stage, two reference objects were selected, namely: areas of boreholes No 10 and 22, where ground geophysical observations were conducted, soil, rock and water samples were taken, and laboratory studies of their physical and mechanical properties and chemical composition were performed. At the third stage, the features of the deep geological structure of the deposit were studied, on the basis of the results of the above-mentioned investigations and with the involvement of additional information, the hydrogeological

features of the section were established, the reasons that led to the deformation of the casing in the studied wells were analyzed, and the area of the most potentially probable spread of the landslide process in the vicinity was determined around borehole No 10 (Fig. 1.). Table 1 shows the physical and mechanical parameters for all lithological types of soils and rocks. Table 2 shows the values of the calculated indicators that were used to estimate the slopes.

Figure 1 *Space photo of the surface in the area of borehole No 10.*
а - the location of the borehole; б, в - the detachment plane of the "old landslide"; г – deformation terraces on the surface of the landslide relief; д, е - swampy area on the slope from borehole No 10; є - the bedrocks outcrops; ж - sampling for determination of physical and mechanical properties.

Table 1 Physical and mechanical parameters

No	Rock type	Bulk density, δ (g/cm³)	Speed of longitudinal wave, P (m/sec)	Speed of transverse wave, S (m/sec)	Bulk modulus, E (mPa)	Effective friction coefficient, μ	Shear modulus, G (mPa)
1	*Coarse sand*	2,03	1836	250	6,6859	0,491	0,129
2	*Fine sand*	1,98	1742	382	5,6877	0,469	0,321
3	*Silty sand*	1,91	1711	503	5,1182	0,453	0,504
4	*Sand-soil mixture*	1,83	1677	457	4,6812	0,457	0,393
5	*Sand-clay mixture*	1,56	1552	379	3,4152	0,461	0,281
6	*Sand-clay mixture of increased moisture*	1,58	1578	409	3,5781	0,463	0,273
7	*Wet clay*	1,43	1535	364	3,172	0,478	0,143
8	*Wet clay*	1,42	1519	287	3,1476	0,48	0,132
9	*Weathered mudstone*	1,96	1833	354	3,1234	0,47	0,142
10	*Weathered mudstone*	1,96	1985	360	7,385	0,4778	0,254
11	*Weathered mudstone*	2,14	1755	489	5,9107	0,4469	0,512
12	*Loam*	2,08	1735	512	5,5361	0,4402	0,545
13	*Mudstone*	2,14	1755	489	6,3077	0,4539	0,469
14	*Siltstone*	2,27	3274	2064	11,4972	0,1953	9,679
15	*Sandstone*	2,23	3142	1931	10,9575	0,2124	8,314
16	*Sandstone*	2,05	2616	1505	7,8407	0,2521	4,641
17	*Sandstone*	2,38	3330	2500	6,6023	0,0384	14,863

Table 2 Values of calculated indicators for assessing slope stability

Rock type	State of the surface	Bulk density, kg/cm³	Shear resistance	
			φ,grad.	C, mPa
Weathered mudstone		1,96	4,5	0,165
		1,98	4,6	0,153
Loam		2,15	10,5	0,52
		2,05	6,45	0,012
Sandstone		2,35	28-32	4,38
Contact surfaces				
Sandstone	Dry		26 - 35	0 - 0,049
	Wet		24 - 32	0 - 0,029
Mudstone - Sandstone			8,6	0,0018
Mudstone - Siltstone			2,8	0,0022
Loam - Mudstone			12,8	0,0002

The landslide processes in the areas where the boreholes are located, related to the consequences of their drilling and surface facilities of the field and the development of oil and gas accumulations, are provoked by deep tectonic movements and neotectonic activity of this territory. The highest intensity of tectonic movements is observed within the Berehovy Nappe, the lower one corresponds to the steep subthrust limbs and areas of deep folds not covered by the thrust, and the lowest ones occur in sloping fold limbs.

Conclusions

1. Based on the analysis of natural hydrogeological features of the upper part of the section, geometric characteristics of slopes, physical and mechanical properties of soils and bedrock, mathematical modeling, it was established that there are no causes for the formation of natural surface landslide processes for the studied territory.
2. Surface landslide processes in the areas where the boreholes are located, associated with the consequences of the construction of the wells and the surface facilities as well as the development of oil and gas fields, are provoked by deep tectonic movements and neotectonic activity of this area.
3. The main reason for the deformation of the boreholes is discontinuous disturbances of various genesis and rank (thrusts, faults, zones of increased fracturing) and lithologic-stratigraphic boundaries of the Vorotyshcha, Polyanytsia, and Menilite formations.
4. It was found that the highest intensity of tectonic movements is observed within the Berehovy Nappe, the lower one corresponds to the steep subthrust limbs and areas of deep folds not covered by the thrust, and the lowest ones occur in sloping fold limbs.
Berehovy Nappe is characterized by the greatest intensity of tectonic movements, the steep wings of the subthrust and areas of deep folds not covered by the thrust correspond to the lower, and the lowest are characteristic of the gentle wings of the folds.
5. It is recommended to carry out the geological and geophysical monitoring (twice a year - spring and autumn) in order to control the possible activation of landslide processes, including the ones caused by the man-made load on the slopes, which lead to the violation of springs, discharge zones and filtration of natural (underground and surface) and technological waters.
6. When choosing the locations of new exploration and production boreholes, it is recommended to conduct a targeted engineering and geological survey of the sites using the developed equipment and methodical complex in order to assess the possibility of the occurrence of sliding processes caused by both the features of the upper part of the section and the deep structure.

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