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Engineering and Geodynamics Conditions of Economic Development and Construction on Landslide Slopes in Odesa Coast

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SUMMARY

Purpose of the work has been to reveal spatial and temporal regularities of micro-block geodynamics to bring down engineering and construction risks on landslide slopes of Odesa coast. **Methodology.** The results of the slope landslide mapping (1953), geodetic monitoring (1966 – 1992) and instrumental measurements of deformations (2018) of constructive elements of an offtake drift in Odesa coast landslide protection works have been used as the source data. Data processing comprised determination of benchmarks' movement and horizontal displacement, incline parameters of the offtake drift water-sink and deviation of the drift cross sectional diameters from the standard one. **Results**. It has been established that the drift could be divided into separate segments (blocks of rock massif), which experience rises, inclinations and differentiated movements. The deformations of the drift water-sink and constructive elements that have accumulated during service life are well pronounced. They have the form of zones of local creepage formed as the result of micro-blocks differentiated movements. **Conclusions.** The structural and geological basis of landslide processes is permanently active as the result of micro-blocks constant movements creating conditions for the slopes stability decrease. Optimal construction solutions should be tailored for current engineering geodynamics of landslide slopes.

Introduction. Study of Odesa coast landslides and experience of landslide protection have a long history [Zelinsky et al, 1993, Budkin et al, 2000, Cherkez et al, 2012]. Our studies in the past decades show that the leading role in forming, development and dynamics of landslide processes is played by micro-block structure of geological section upper part. [Cherkez et al, 1997, 2012, Kozlova et al, 1998, 2013]. It has been established that the differentiated tectonic movements of micro-blocks, as well as alternation of zones of modern compression and transtension form the prerequisites for slopes stability decreasing, including the parts of coast with coast-protection and landslide protection works [Cherkez et al, 2012, 2013, Kozlova et al, 2013]. Combination of factors and reasons for dynamics of slopes deformation development as a single natural and technogenic system are not known for a fact and are not taken into account in current assessments of engineering and geodynamic effectiveness of protective measures. Experience of geodetic monitoring and instrumental measurements of constructive elements deformations in Odesa coast landslide protection works has shown effectiveness of this method to study discretization of rock massifs and establish spatial and temporal dynamics of blocks [Cherkez et al, 2012, 2013].
The purpose of the work is to reveal spatial and temporal regularities of micro-block geodynamics to bring down engineering and construction risks on landslide slopes of Odesa coast.

Data & Methods. Landslide protection works include underground collector drains and offtake drifts (Figure 1A). Their lining consists of tubbing sections 0.75 m wide connected in the form of rings with diameter 2.2 m. Those flexible subhorizontal linear structures are quite long (0.3-0.5 – 5-10 km) and reflect sensitively the character of deformation processes inside the massif.

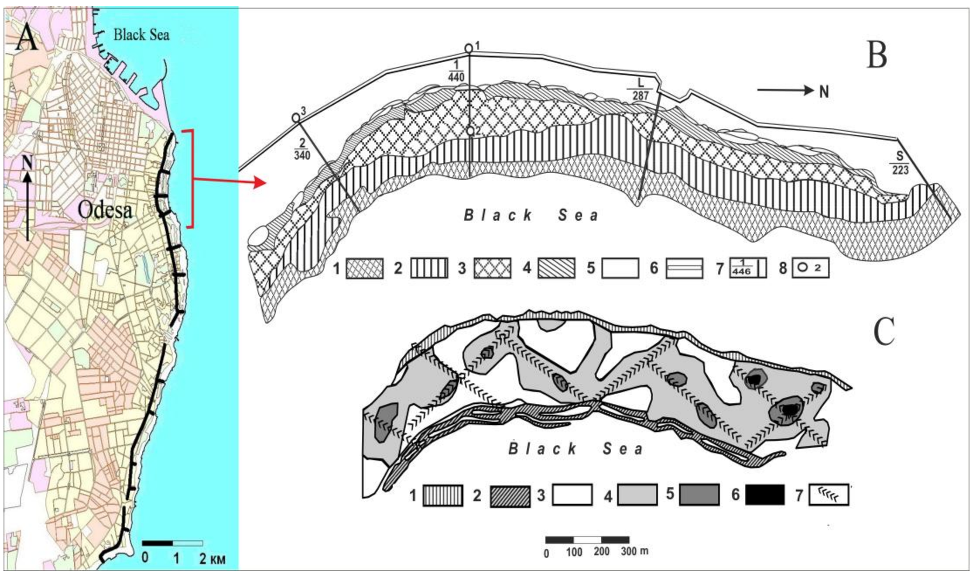

Figure 1. A – Layout of drainage facilities (drains and offtake drifts are showed in thickened line) of Odesa coast landslide protection works. B – landslide slope of a segment of Odesa coast; 1-4 – landslide benches formed in different times by deep pressing-out landslides with displacement surface in Meotian clays; 5 – landslides of loess; 6 – collector drain; 7 – offtake drift, its number (name) and length in meters; 8 – technological shaft and its number. C – Outline of specific density and length of fractures on the slope from the landslide survey data (after landslide in 1953); 1 – slid segment of plateau; 2 – pressing-out ramp; 3-6 mean length of landslide fractures, m: 3 - < 20; 4 – 20-40; 5 – 40-60; 6 - > 60; 7 – zones weakened by fractures.

To study the dynamics of deformation processes and reveal high-frequency discretization of geo-space the data of geodetic observations and instrumental measurements performed in the offtake drift No.1 (Figure 1B) have been used. The drift has total length 440 m, it was mined through landslide accumulations (233 m) and rock (207 m), where it enters collector drain. Deformation of the drift was determined be measurement of vertical movements and horizontal displacements of the benchmarks embedded in reinforcing elements. Altogether 20 cycles of geodetic measurements were performed in the period from 1966 to 1992. In each cycle of measurement when processing the levelling data we determined relative variation of subsea depth of each benchmark in relation to the one located the deepest inside the rock massif. That revealed vertical deformations of the drift's 'body', which accumulated by the time of respective cycle of observation. In 2018, the authors performed measurement of deformation of constructive elements of drift No.1 (Figure 1. B) accumulated during service period (1964 - 2018): - topographic elevation of the drift water-sink by geodetic levelling at intervals 2-5 m with SOCIA laser automatic tacheometer, precision ± 1.0 mm. Variations of the water-sink benchmarks were determined with reference to the point at the inlet; - diameter of the drift in vertical and horizontal directions with laser distance meter Leica Disto A3, precision ± 2.0 mm, on 513 rings of tubing at intervals 0.75 m along the drift. Methodology of processing of the data from measurements of the drift constructive elements' deformations and displacements included transformation of the source data series into equidistant ones with 0.5 m interval, which corresponds to the intervals of tubing rings diameter measurements. Using the method of sliding averaging with 30 m window we determined the trend component and the remainder set of calculated parameters of drift water-sink's inclination and the deviation of horizontal and vertical diameters of tubing rings from the standard one (2200 mm). To establish the high-frequency periodic component of the reminder set spatial variability spectral analysis (Fourier transformation) was used.

Results. The biggest frontal pressing-out landslide in Odesa coast with length over 2 km along the coastline happened in 1953. The landslide slope on that segment of the coast is formed by deep pressing-out landslides and consists of four landslide benches 50-100 m wide with displacement surface having mark -13.0 m below the current sea level (Figure 1B). Based on mapping of the fractures that formed as the result of landslide the regularly orientated (NE and NW) system of fracture-weakened zones was revealed (Figure 1C). It should be pointed out that their directions do not coincide with general directions of vectors of landslide displacements and boundaries of landslide benches, which enables us to connect them with tectonic-lineament regmatic net [Lomakin et al, 2016]. At that, activeness of diagonal net is 'suppressed' by the influence of orthographic strike of the seacoast. It could be supposed that due to differential movements of blocks of different hierarchic scale not only in the landslide slope, but also in rock massif, formation of zones of local plastic deformation takes place, i.e. a structural-geological basement of landslide processes is created and being maintained active by tectonic processes.

Analysis of data on vertical movements and horizontal displacements of the benchmarks embedded in reinforcing elements of the drift No.1 (Figure 2A) shows that some of those benchmarks experience mainly rising, while other - subsidence. Therefore, the drift could be divided into separate segments (blocks of rock massif), which experience rises, inclinations and differentiated movements. Displacement of benchmarks in time have well-pronounced periodic character (Figure 2D). In general, the accumulated deformations have the form of indulating bands with wavelength from 60 to 120 m. Analysis of horizontal deformations along the drift shows that the distance between benchmarks is increasing and the drift is elongating. The most significant elongation takes place within the landslide accumulations (327 mm) due to slow 'spreading' of landslide bench, as well as in the part where landslide body joins the rock massif. Those tensile phases, stable in time, were found in the segments of the drift where vertical movements of benchmarks are characterized by negative sign. Elongation of the drift in the rock massif made 216 mm. Many years' average speed of benchmarks longitudinal displacement in the rock make 5 - 8 mm/year, while in landslide accumulations – 12 - 15 mm/year. The data presented point out that horizontal displacements of benchmarks and elongation of parts of the drift mined through the rock are caused by reological properties of the main deformed level – Meotian clays. The deformations (ΔH) that accumulated during service time of the drift water-sink relief (Figure 2B) show well-pronounced periodic character and represent zones of local plastic deformations that have formed as the result of differentiated movements of the existing and potential landslide blocks.

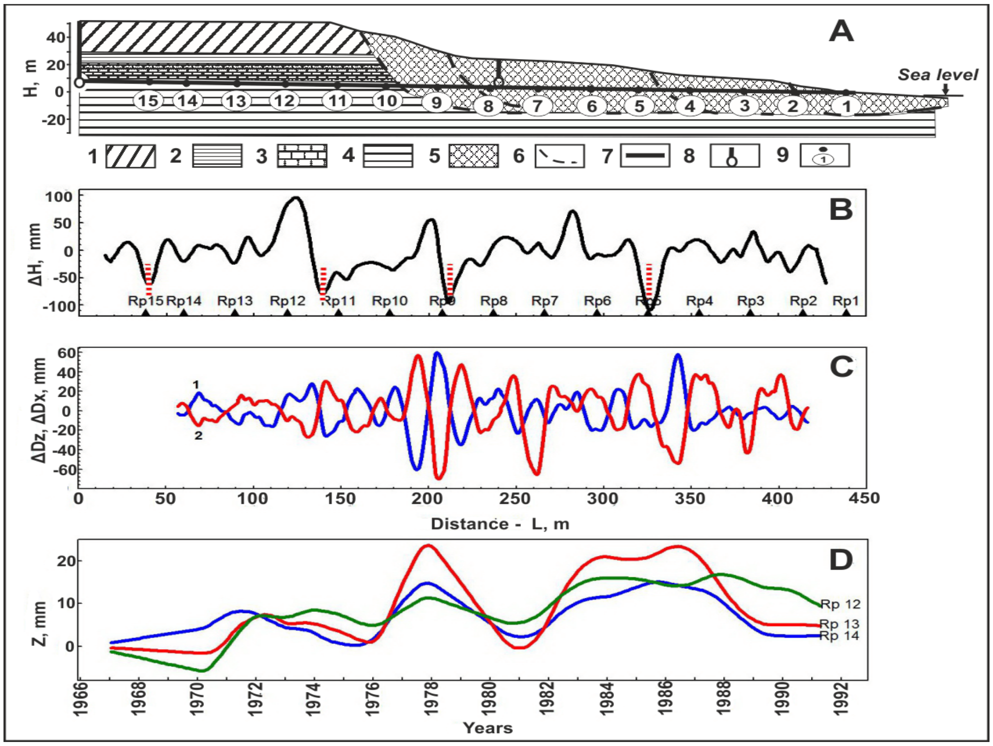

Figure 2. A – Schematic geological record along the drift No.1. 1 – Quaternary loess loam; 2 – Pleiocene red-brown clays, 3 – Pontian limestones, 4 – Meotian clays; 5 – landslide accumulations; 6 – surface of landslides displacement; 7 – offtake drift; 8 – technological shaft; 9 – geodetic benchmark and its number. B – reminder set (after taking the trend component) of calculated parameters of the drift water-sink inclination (red dotted line – boundaries of existing and potential landslide blocks). C – reminder set (after taking the trend component) of deviation of horizontal (1) and vertical (2) tubing rings diameters from standard (2200 mm). D – interannual dynamics of benchmarks vertical displacements in the drift located in rock massif of the slope.

Maximal positive values of deformation correspond to the places of plastic pressing-out of clay of the main deformed level, while minimal – to the places of active manifestation of existing landslide blocks' displacement within the slope and forming of potential surfaces of landslide displacement within rock massif. Spectral analysis of spatial distribution of ΔH parameter size shows that it corresponds to spatial periods 80 – 120 m and 24 – 36 m. In the period of the drift construction according to technological conditions the internal diameter of tubing was 2200 mm. This figure is taken as the starting value and using deviation from it, we determined deformation of the drift cross-section in vertical and horizontal direction (Figure 2C) for the service life period (1966 – 2018). In physical sense decreasing of vertical diameter of the tubing rings and respective increasing of horizontal diameter speaks for differentiated vertical movements of adjacent blocks, while in the segments where relative increasing of vertical and decreasing of horizontal diameter, horizontal (along the coastline) movements of adjacent blocks take place with different speed. Spectral analysis of the values of parameters ΔDx and ΔDz, which characterize spatial distribution of vertical and horizontal deformations of tubing rings along the drift shows the period 24 – 30 m. The last coincides with the periods established using spatial set of the drift water-sink relief deformations (ΔH). This could mean that the deformations of constructive elements and 'body' of the drift subordinate to a single reason – quasi-periodical deformation of the rock massif.

At present designing practice ***a priori*** adopts the assumption that immovability of rocks below the marks used at construction on plateaus and landslide slopes of piled foundations on condition that normative stability of the slope is ensured. This assumption does not envisage certain tension in construction due to 'forced' deformations and movements caused by movement of blocks of different order. Movement of the blocks can cause deformations in constructions even during the stage of building. This is especially important when we speak about 'dense' development with high buildings close to the crest of plateau, as this part reacts sensitively to combinations and interactions of a broad spectrum of natural and technogenic factors.

Conclusion. It has been established that differentiated micro-block movements, as well as interchange of zones of modern compression and extensions create prerequisites for decreasing of slopes stability. That is why forming of zones of local plastic deformation takes place not only in landslide slope but also in rock massif. As the result, structural and geological basis of landslide processes is created and maintained permanently active. Constructive development of Odesa coast landslide zone causes the necessity to take into account engineering and geological conditions in the area where a set of landslide and coast protection measures are being taken. It is evident that optimal construction solutions shall contribute to engineering and geological effectiveness of the existing complex of coast and landslide protection works and be tailored for current engineering geodynamics of landslide slopes. For any type of the landslide slopes' constructive development complex spatial character of displacements system in the rock massif and peculiarities of geo-deformation processes dynamics are to be taken into consideration.

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