Rotational dynamics and deformation processes in the mass of rocks according to geodetic monitoring data (on the example of Odesa territory)

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SUMMARY

To reveal interrelations of local deformation fields within the territory of Odesa and variations of inter-annual rate of the Earth rotation. Methodology. The results of monthly geodetic monitoring have been studied: a) landslide slope and the near-shore part of the plateau within the territory of Primorskiy Boulevard in Odesa (mid-1960s - end of the 1990s), b) the territory of Novo-Arcadiiskiy residential area in Odesa (2004-2007). Analysis was carried out using the methods of general statistical analysis, frequency-harmonic Fourier analysis, seasonal analysis. Results. Close relationship has been revealed between the local deformation fields of two observation sites spaced apart within the city with intra-annual variations in the Earth's rotation rate. Conclusions. Geodetic monitoring of the territory of Primorskiy Boulevard and the Novo-Arkadiiskiy residential area provides direct evidence of quasi-periodic relative vertical displacements of benchmarks in these areas correlating with variations in the Earth's rotation rate (LOD) in the intra-annual cycle. An important practical consequence of the results received is that the most high-frequency disjunctive network is constantly in the regime of different-frequency activation caused by rotational dynamics, which shall be taken into account even on the scale of local engineering and geological surveys for construction of individual buildings and structures.

Introduction. Studies of recent decades have shown that the microblock structure and high-frequency geodynamics of the earth's crust play a leading role in the formation of geological environment properties, which serve as the basis for engineering structures [Cherkez et al., 1997, 2012, 2013, 2014; Kozlova, 2000, 2001, 2003; Kozlova et al., 1998, 2013, 2016, 2019; Shmouratko, 2001; Shmouratko et al., 2013]. In this regard, the question of the factors influencing the variability of the stress-strain state of rocks is important. One of these factors can be rotational - a change in the speed of the Earth's axial rotation or the length of the day (Length of the Day, LOD). It is proved in the works [Cherkez et al., 2012; Shmouratko, 2001], based on the analysis of the average monthly altitudinal position of the groundwater level along the regime network of observation wells in Odesa over a 30-year period, that the intra- and inter-annual dynamics of groundwater level is controlled mainly by the rotation-caused variability of stress-strain state of the Post-Sarmatian rock massif's structural-geophysical stage. At the same time frequency characteristics of the stress-strain state of rocks correlate with the structural-tectonic (system of disjunctive lattices) features of the city territory. The relationship between the intra-annual dynamics of drainage structures flow rates, the levels of the Pontic aquifer in the territory of Odesa and the Earth's rotation rate is also indicated in [Bunyak, 2013]. If this is true, then the influence of the rotation factor should manifest itself in the dynamics of microblocks vertical displacements on the territory of Odesa.
The purpose of the work was to reveal interconnection between local deformational fields within Odesa territory and the variations of inter-annual rate of the Earth rotation.

Data & Methods. To identify the modern high-frequency geodynamics of the earth's crust, the results of geodetic monitoring were studied: a) the landslide slope and the near-edge part of the plateau within the territory of Primorskiy Boulevard in Odesa (from the mid-1960s to the end of the 1990, performed by the State Regional Geological Enterprise "Prichernomorgeologiya"), b) the territory of the Novo-Arcadiiskiy residential area in Odesa (2004-2007, performed by the Odesa State Academy of Civil Engineering and Architecture) (Figure 1A).

Figure 1 *Scheme study areas location (A); Location of geodetic benchmarks in the Primorskiy Boulevard area (B) and observation marks in the houses of the Novo-Arcadiiskiy residential area (C) in Odesa*

In different years 63 benchmarks were set on the territory of the landslide slope of Primorsky Boulevard between the Vorontsov Palace and the City Council House (Figure 1B), along which geodetic observations of the vertical and horizontal displacements of benchmarks were carried out during 1965-1997 with different periodicity and in different time intervals. Continuous monthly time series are available for only 5-6 benchmarks, the rest were observed irregularly.

On the territory of the Novo-Arkadiiskiy residential area in Odesa 22 cycles of geodetic observations of the marks subsidence were carried out during the period from 12/18/2004 to 12/29/2007 (intervals between observation cycles were from 10 to 75 days) [Kozlova et al., 2016]. Figure 1C shows the location of the observation marks in the buildings of the Novo-Arcadiiskiy residential area. Analysis of time series of geodetic benchmarks and observational marks vertical displacements was carried out using methods of general statistical analysis, Fourier frequency-harmonic analysis, seasonal analysis. Time series of the Earth's axial rotation velocity were used (data from *http://hpiers.obspm.fr/eop-pc/*).

Results. In the Primorskiy Boulevard area the landslide slope about 100 m wide with steepness of 14-16 degrees is kept in a relatively stable state by a system of anti-landslide structures (retaining walls and counterberms) built in the first half of the 19th century. At the base of the slope a technogenic complex of the Primorskaya Street and berthing facilities of the Odesa Port are located. Despite the performed anti-landslide measures, the slopes of the Primorskiy Boulevard have been experiencing landslide deformations for many decades, as evidenced by the cracks in the plateau, deformations of retaining walls, decommissioning of the escalator lift and other facts [Kozlova et al., 2013]. Before opening of the Stambulskiy Park and the Grecheskiy Park in 2017 – 2018, reconstruction of the existing and construction of new protective structures were carried out. Analysis of benchmarks' vertical displacements on the territory of the Primorskiy Boulevard allows us to state that most of the benchmarks have a tendency to subsidence with an average long-term rate of about 3-4 mm/year. On the background of a general negative trend, quasi-cyclic changes in the sign of vertical displacements are clearly manifested, both in the intra-annual cycle and with periods from 2 months to 11 years. Differentiated (multidirectional) movements of benchmarks located at a distance of only 15-30 m from each other are often being recorded. However, it remains the case that the changes in the benchmarks movement direction occur in the same seasons of the year synchronously with the rotational dynamics (Figure 2).

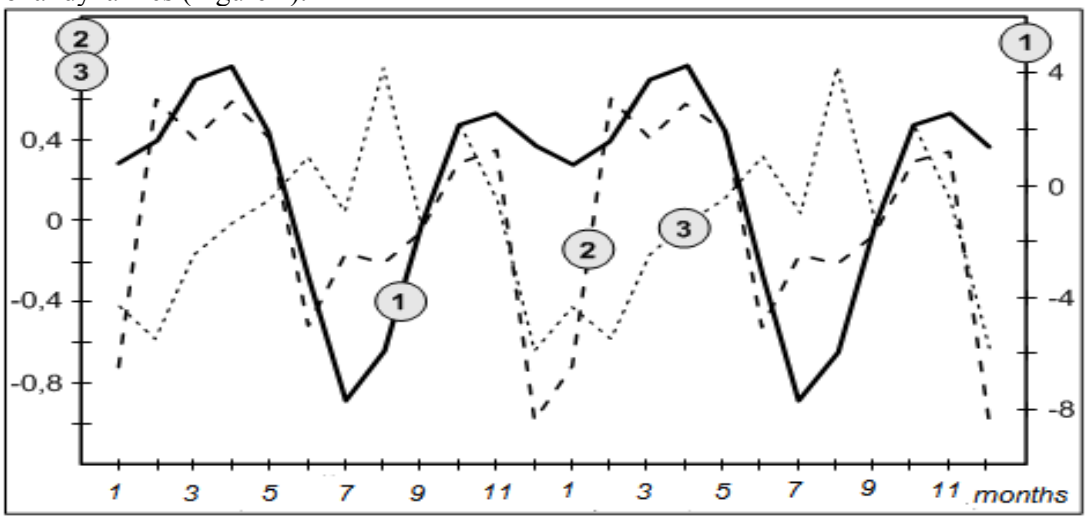

Figure 2 *Intra-annual dynamics of vertical movements of the geodetic benchmarks located on adjacent microblocks within the landslide slope (Primorskiy Boulevard) and the speed of the Earth's axial rotation. 1 - seasonal component of the time series of the day length deviation from the standard (86400 s) (in ms) [IERS EOP PC data], calculated coming out of time series from 1975 to 1997; 2 - the seasonal component of the vertical subsidence of the benchmark R1-5 (in mm/month), calculated coming out of time series from 1975 to 1997; 3 - the same for the benchmark RP2-1115*

Spectral analysis revealed that the structure of most of the analyzed time series of benchmarks vertical displacements has linear character, i.e. it has isolated maxima at certain frequencies. In the intra-annual periodicity of benchmarks displacements the most stable periods are 7.2; 6.0; 4.8; 3.3 and 2.6 months, i.e. close to the characteristic periodicity of the Earth's rotational regime [Kozlova et al., 2013]. These facts indicate that the course of the benchmarks vertical movements is significantly

influenced by quasi-cyclic variations of the stress-strain state of the soil mass. The displacements of observation marks within the buildings of the Novo-Arcadiiskiy residential area, in different observation cycles are characterized by different rates and are in the range of 1.0 - 10.0 mm/month. Analysis of the observational marks dynamics within the buildings of the Novo-Arkadiiskiy residential area enabled us to identify a seasonal cycle similar to one of the Primorskiy Boulevard in the mode of marks' vertical movement (Figure 3).

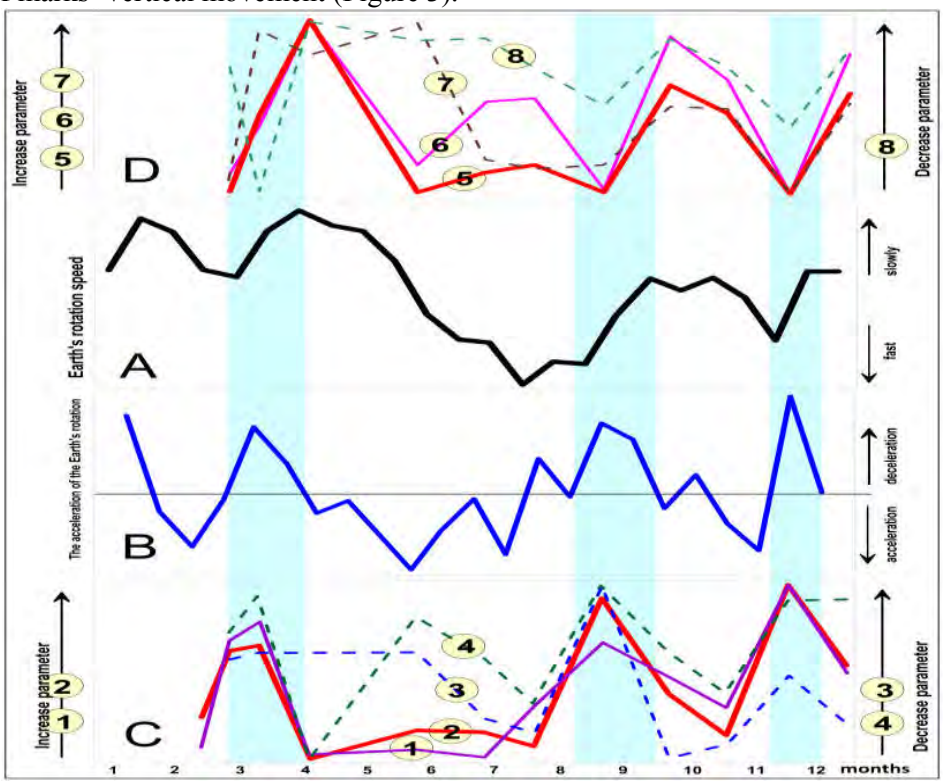

Figure 3 *Intra-annual dynamics of observational marks in the building of the Novo-Arcadiiskiy residential area in 2007. A - Change in the speed of axial rotation of the Earth; B - Change in the acceleration of the axial rotation of the Earth; C - Variations in the speed of vertical movement of observation marks: 1 - maximum speed of lowering of observation marks; 2 - average speed of lowering of observation marks within the building pattern; 3 - maximum speed of observation marks raising; 4 - the total square of those areas within the building pattern where the observation marks are raising; D - Variations in the acceleration of the observation marks vertical movement; 5 - average positive acceleration of the observation marks within the building pattern; 6 - total square of those areas within the building pattern where the observation marks experience positive accelerations; 7 - maximum positive acceleration of observation marks; 8 - maximum negative acceleration of observational marks. All the curves are normalized*

The dynamics of the observational marks' vertical displacements in 2007 shows a close relationship with changes in the speed and acceleration of the Earth's axial rotation. This suggests that deformations of building foundations are "subordinated", to one degree or another, to the rotational stress field through the differentiated movements of the Pontic limestone microblocks.

Conclusions. Geodetic monitoring of the Primorskiy Boulevard and the Novo-Arkadiiskiy residential area territory provides direct evidence of quasi-periodic relative vertical displacements of benchmarks and observational marks in those areas correlating with variations of the Earth's rotation rate (LOD) in the intra-annual cycle. An important practical consequence of the results obtained is that the most high-frequency disjunctive network is constantly in the mode of activation with different frequencies,

obeying the laws of rotational dynamics, which shall be taken into account even on the scale of local engineering and geological surveys for construction of individual buildings and structures.

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