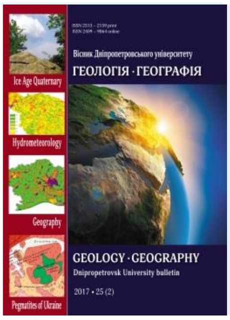

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On some aspects of modeling geodynamic risk in the territory of distribution of subsident soils

T.P. Mokritskaya, K.A. Samoylych

Oles Honchar Dnipro National University, Dnipro, Ukraine, e-mail:mokritska@i.ua

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Abstract. In modeling geodynamic risk, the issues of developing special models of risk on the territories of distribution of loess and loess-like subsident soils under technogenic impact are of great relevance. Developing such models is a multi-stage process, which requires developing a model of the geological structure of a studied massif and setting predicted values of the properties of loess soils for preliminary quantitative evaluation of possible deformations in the natural conditions and in the zone of impact of constructions. Standard quantitative evaluation concerning the subsidence is carried out using results of testing the sample in limit states. Prognosis of the degradation of subsidence properties as a result of the break-up of the microaggregates in the zone of aeration is possible in conditions of impact of changes in the microaggregate compound on the subsidence. Using the method of defining the granulometric composition of the soil allows one to determine the area of soil condition in relation to dispersity. The method of GMDH allows one to develop a mathematical model of degradation of subsidence properties and calculate the predicted values of deformation in the zone of insufficient water content. The degradation of the subsidence properties of subaerial horizons is manifested most significantly at mild (30% of possible) increments of moisture and pressure of 0.1 mPa. In the area of additional pressure, predicted values of deformation insignificantly increase under moisture due to degradation, with increased moisture the break-up of the aggregates of sand fraction is followed by increase in the number of aggregates of smaller size (large-grained pulverescent ΔA^3). The content of free thin fine-grained sandy (ΔM^2), and clayey particles (ΔM^5, ΔM^6) increases, connected with aggregates of thin fine-sandy and large-grained clayey. The share of aggregates of large-grained pulverescent fraction also increases; the content of particles of this fraction assembled in the aggregates decreases. The dependency of deformation intensity in conditions of degradation of paleosol is of another character: the intensity of degradation increases as the pressure rises. The analysis of predicted values of aggregate content, free and assembled particles when there is change in moisture conditions showed that the process of the break-up of thin fine-sandy aggregates and increase in the share of large-grained clayey aggregates (composed of thin fine-sandy particles) is followed by occurrence of free particles of thin fine-sandy and thin clayey fractions.

Keywords: loess, microaggregate composition, degradation, model

О некоторых аспектах моделирования геодинамического риска на территориях распространения просадочных грунтов.

Мокрицкая Т.П., Самойлич К.А.

Днепровский национальный университет имени Олеся Гончара, Днепр, Украина, e-mail:mokritska@i.ua

Резюме. При моделировании геодинамического риска актуальными являются вопросы создания пространственных моделей риска на территориях распространения лессовых и лессовидных просадочных грунтов, подвергающихся техногенному воздействию. Создание таких моделей – многоступенчатый процесс. Необходимо создать модель геологического строения массива, задать прогнозные значения свойств лессовых грунтов для предварительной количественной оценки возможных деформаций в природных условиях и в зоне влияния сооружений. Стандартная количественная оценка относительной просадочности выполняется по результатам испытания образца в предельных состояниях. Прогноз деградации просадочных свойств из-за распада микроагрегатов в зоне аэрации возможен при условии влияния изменений микроагрегатного состава на просадочность. Привлечение методики определения гранулометрического состава грунта (Рященко Т.Г., [11]) позволяет установить область состояний грунта по дисперсности. Метод МГУА позволяет построить математическую модель деградации просадочных свойств, найти прогнозные значения деформаций в зоне неполного водонасыщения. Максимально выражена деградация просадочных свойств субаэрального горизонта при умеренном (30% от возможного) приращении влажности и давлении 0,1 МПа. В области дополнительных давлений прогнозные значения деформаций за счет деградации незначительно увеличиваются при увлажнении, распад агрегатов песчаной фракции при росте влажности сопровождается увеличением количества агрегатов меньшего размера (грубопылеватых ΔA^3). Увеличивается содержание свободных тонкомелкопесчаных (ΔM^2), глинистых частиц (ΔM^5, ΔM^6), связанных в агрегаты тонко-мелкопесчаных и грубоглинистых.

Доля агрегатов крупнопылеватой фракции также увеличивается, содержание связанных в агрегаты частиц этой фракции уменьшается. Зависимость интенсивности деформации при деградации палеопочвенного грунта имеет другой характер: с ростом давления увеличивается интенсивность деградации. Анализ прогнозных значений содержания агрегатов, свободных и связанных частиц при изменении состояния по влажности показал, что процесс распада тонко - мелкопесчаных и увеличения доли грубоглинистых агрегатов (состоящих из тонкоглинистых частиц) сопровождается появлением свободных частиц тонко-мелкопесчаных и тонкоглинистых фракций.

Ключевые слова: лесс, микроагрегатный состав, деградация, модель

Introduction. The notion geodynamic "risk" is related to the calculation of possibility of damage, vulnerability (Osipov et al, 2017). Geodynamic risk can be defined as the possibility of development of catastrophic, unfavourable or dangerous geological processes. The objectivity of risk calculation is related to the duration of the observations, the level of study of the cause-effect relationship (Bles et al, 2009). In areas with loess, loess-like deposits, technogenic impact leads to degradation of subsidence properties and deformations (Narymanyants et al, 2004). Subsidence is a significant downward shifted deformation, caused usually by two factors: moisture and pressure (Muñoz-Castelblanco et al, 2012). Degradation of subsidence is the process of directed change in the microaggregate composition (Mokritskaya, 2015). Standard quantitative calculation of subsidence is performed using results of experiments; testing of samples is made in limit states of moisture and pressure. After supplementing the results of the experiment with data on increment of content of particles and aggregates, a connection between evolution of microaggregate composition and subsidence can be found. In this case, the algorithm of developing models of risk conditioned by the degradation can be described with the following sequence of the stages: experimental defining of the area of changes in the microaggregate and granulometric composition, indicators of subsidence of soils; developing a mathematical model of connection between dynamics of microaggregate composition and values of relative subsidence; prognosis of degradation of subsidence properties in set conditions; developing a special model of subsidence degradation.

This article covers the issues of experimental calculation of indicators of degradation of subsidence properties as a result of changes in the microaggregate composition and certain aspects of developing a mathematical model of predicting the degradation of subsidence properties of a particular stratigraphic-genetic soil horizon.

Literature review. Subsidence refers to "deformation of loess sediments caused by their own weight due to moistening" (Larionov, 1959), "collapsing-incremental deformation in loess sediments" (Krayev, Kostyanoy, 1980). Works by Kriger N. I. (Kriger, 1965) describe their most significant peculiarities: "adaptability of loess properties in relation to geological environment" and "self-defense". Here it is mentioned that these sediments are capable of "degradation", which the author refers to as "compacting, loss of subsidence properties, vanishing of typical texture, leaching". The impact of evolution of microaggregate composition on the degradation of subsidence, in the process of moisture increase in the aeration zone, has been insufficiently studied.

Searching for connections between the structure of sediments and their geomechanical properties is relevant in different areas of application in geology (Dong et al, 2017). Mokritskaya and Koriashkina (Mokritskaya, Koriashkina, 2013) describe variants of predicting relative subsidence. At this stage of developing a model, it is recommended that the direct indicators (classificational and extensive) should be selected as variables – density of soil phases, natural moisture, boundary flexibility, content of fractions. In standard definitions of granulometric composition, pulverescent and clayey fractions are only crudely distinguished, which does not allow accurate description of the connection between evolution of microaggregate composition in the process of subsiding and subsidence. Applying the method described in (Ryaschenko, 2010) allows one to identify the area of soil condition in relation to moisture.

Geodynamic risk in the areas of distribution of loess soils is to a large extent related to the peculiarities of their deformation. Current research on deformational processes in soils is focused on studying microstructure using methods of tomography, computer diagnostics of images (Miguel et al, 2017; Wu et al, 2017). The process of subsidence is traditionally evaluated using the change in the coefficient of porosity as a result of moisture and pressure transfer (Abelev, 1936). The deformations in conditions of insufficient water content are studied through methods of physical modeling (Delwyn et al, 2011; Yang et al, 2017). The work (Wang et al, 2017) describes the process of consolidation of dispersive soils in conditions of insufficient water content through the system of differential equations, which are approved in the detailed study of microstructure. In description of the deformational processes in soils with complex character of deformation (capable of catastrophic reactions), new models of soils, theory of fractals in particular, are applied (Russell, Buzzi, 2012; Russell, 2011; Mokritskaya et al, 2016).

Methods. A prognosis model of the relative subsidence of a particular stratigraphic- genetic horizon can be obtained as a model of evolution of its physical state (Mokritskaya, 2013) and dispersity as a result of moisture. The values of relative subsidence are calculated by standard compression tests of soil at two limit moisture states of the soil (Delage et al, 2005). The area of soil condition in relation to dispersity is experimentally (Mokritskaya, Samoylich, 2016) identified through the number of particles of pulverescent and clayey fractions at different methods of preparation. The group method of data handling (Ivakhnenko, Yurachkovsky, 1987) permits analysis of the character of connection between the variables which characterize the condition, and the construction of a model. Setting the predicted condition of subaerial loess and paleosol horizons, one can calculate the value of relative subsidence of a horizon at the set stage of evolution of dispersity.

The algorithm of prognosis of subsidence degradation is peculiar in that the variables use relative increment of fraction content. Choice of variables should be acknowledged, for example, by the results of non-parametric correlational analysis of relations between the changes in dispersity and the values of deformation. Boundary values of moisture and other variables of the models were set through three-termed gradation of the frequency in a specially constructed scale, the length of which is calculated using the interval of the moisture increment which is theoretically possible for the soil. The predicted value of degradation increment for each limit state is calculated using the group method of data handling with the programme of L Koriashkina.

Results. We considered different variants of setting the values of variables. The first variant calculated the increment of particles, comparing dispersity of the sample in natural condition with dispersity "after compression in water-saturated condition" (Table 1 and Table 2). The values are calculated using selective data of small volume (n = 14 - 16). Increase in the moisture of loess-like soil by 30% of possible interval of increments will lead to the break-up of aggregates and release of thin clayey particles. The tendency is stable, and remains during rise of moisture up to 60% of possible interval of increments of moisture (see Table 1).

Table 1. Initial and predicted values of independent variables of the inductive model of relation between the increments of content of certain fractions and relative subsidence of loess loam

Condition	W	W_L	M^{5-A}	M^{11}	M^{6-A}	FM^5	FM^6
1	2	3	4	5	6	7	8
ω_0	0,128	0,25	3,586	2,569	-1,002	-0,366	-0,367
			ΔM^{5-A}	ΔM^{11}	ΔM^{6-A}	FM^5	FM^6
$\omega_{0.3}$	0,164	0,263	0,499	-6,974	-21,881	-0,467	-0,308
$\omega_{0.6}$	0,201	0,276	0,611	-16,516	-24,512	-0,567	-0,377

Notes to Tables 1 - 3:

1. ω, u.f – natural moisture; ρ – density of the soil, g/sm^3; W_L – upper boundary of flexibility of u.f.; average content (ω_0 line) and increase in the content (lines $\omega_{0,3}$; $\omega_{0,6)}$
2. M^{5-A}, % – large clayey particles assembled in aggregates; M^{11},% – free particles of fraction of 2.0 – 0.05 mm; M^{6-A}, % – thin clayey fraction assembled in aggregates; F5 and F6 – degrees of freedom, u.f.
3. A1, A 2, A3, A 5– content of aggregates of fraction of 0.5-0.25; 0.25-0.05;0.05 – 0.01; 0.002-0.001mm.
4. M 2 and M 6 – free particles of fraction of 0.25-0.05 mm and fraction of 0.002-0.001mm.
5. W_0 – initial condition concerning moisture; $W_{0,3}$ – increment of moisture by 30%; $W_{0,6}$ – increment of moisture by 60%;
6. The lines 4 – 6 (Fig.1) and the lines 3-8 (Fig.3) provide: average values (W_0 line); predicted increments of values after compression in relation to the initial condition (lines $W_{0,3}$ $W_{0,6}$).
7. Sign (-) – increase in the content at rise in moisture; sign (+) – decrease in the content at rise in moisture.

Subsidence degradation of paleosol horizon (n = 12 – 20) is expressed as the process of increase in the number of large-grained clayey aggregates, sandy particles and large pulverescent particles assembled in aggregates (see Table 2). The properties of Kaydaksky e PII kd and Vitachevsky e PIII vt paleosol horizons were studied.

Table 2. Initial and predicted values of model variables of degradation of paleosol horizons subsidence

Condition	W	A^2	A^5	M^{3-A}	M^{6-A}	M^2	M^6
1	2	3	4	5	6	7	8
W_0	0,073	5,998	-2,174	-0,118	3,634	-6,586	-1,455
	W	ΔA^2	ΔA^5	ΔM^{3-A}	ΔM^{6-A}	ΔM^2	ΔM^6
$W_{0,3}$	0,132	43,093	-18,618	-38,502	36,152	-29,951	-1,124
$W_{0,6}$	0,191	81,855	-35,365	-73,134	68,670	-50,903	-1,124

Compression tests were performed in standard test tubes according to current Ukrainian standards, at a certain interval of pressures: from natural to additional. Using the group method of data handling

allowed development of a mathematical model of degradation of loess-like subaerial soils and calculation of predicted values of deformation in the zone of insufficient water content (Fig.1). The degradation in the area of pressures lower than the structural robustness (0.1 MPa) is significantly low. Maximum values of degradation of subsidence properties correspond to the area of pressures which are close to the structural robustness – 0.1MPa. The role of increments is insignificant. With moistening, the predicted values of deformation as a result of degradation in the area of additional pressures insignificantly increase. The values of relative deformations are quite high and should be considered during planning.

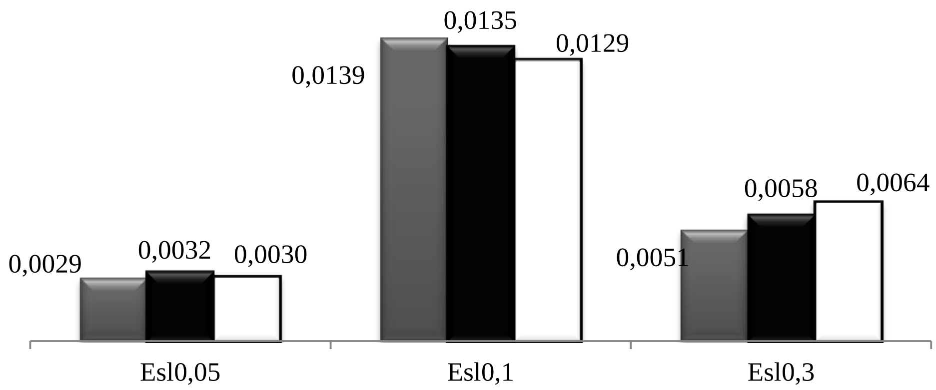

Fig. 1. Predicted values of degradation of relative subsidence of loess subaerial sediments, calculated using the results of experimental calculations of changes in the aggregate composition, free and assembled particles at the stages of pressure of 0.05, 0.1 and 0.3 MPa.

Notes to Fig. 1:

– predicted values of relative subsidence at average moisture of the selection;

– the same at low intensity of increments of moisture;

– the same at mild intensity.

Esl 0.1 – relative subsidence at the pressure stage of 0.1 MPa.

Analysis of the results of prognosis of changes in the microaggregate composition of loess-like soils after compression tests (the second variant of selecting independent variables (Fig. 3), n = 14), indicates that the general tendency remains constant: the degradation is highest at the stage of pressure of 0.1 MPa (Fig. 2). The composition of variables included in the regressors` content in the second variant (Table 3) is selected to characterize positive and negative connections, only direct indicators identified in the experiment were selected.

Table 3. Predicted values of variables of a model of subsidence degradation in loess-like loams

Condition	ω	ΔA^{3}	$\Delta M^{2\text{-}A}$	ΔM^{5}	ΔM^{6}	$\Delta M^{5\text{-}A}$	ρ	ΔA^{1}	ΔM^{2}
$W_{0,3}$	0,155	-3,272	-15,529	-4,217	-4,322	10,903	1,548	13,072	-11,631
$W_{0,6}$	0,202	-9,381	-20,242	-6,088	-6,451	18,052	1,479	17,039	-23,843

Analyzing the values of linear terms of the model leads to the following conclusion: the break-up of aggregates of sandy fraction under increase in moisture is followed by increase in the number of aggregates of smaller size (large-pulverescent ΔA^3). An increase was observed in the content of free-thin fine-sandy (ΔM^2), and clayey particles (ΔM^5, ΔM^6), assembled in thin fine-sandy and clayey aggregates. The process of degradation of subaerial loess-like loams is described as the process of break-up of aggregates formed by thin-grained fine sandy and clayey particles with release of particles. The share of aggregates of large-grained pulverescent fraction increases, the content of this fraction`s particles assembled in aggregates decreases. Both predicted relations between the degradation of loess-like loams indicate the complex discontinuous pattern of the process. The soils in natural condition deform in the area of pressures due to the break-up of aggregates before and after 0.15MPa in different way. In the area of pressures with higher structural robustness, the deformation

due to soil degradation is higher at lower moisture (see Fig. 2), at the initial stage the dependency it is of the reverse character.

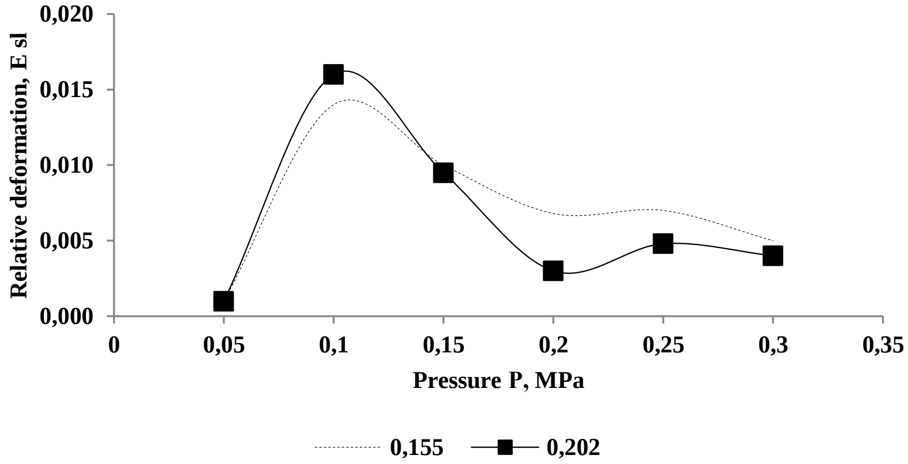

Fig. 2. Predicted values of the degradation of subsidence of loess-like soils at stages of pressure of 0.05 – 0.3 MPA

Notes to Fig. 2:

1. – predicted value of natural moisture of 0.155 f.u. (insignificant change in condition).
2. – predicted value of natural moisture of 0.202 f.u. (mild change in condition).

The relation between intensity of deformation at degradation of a paleosol is of a different character: as the pressure rises, the degradation intensity increases. The degradational process is also discontinuous, although the shifts were manifested only during significant changes in the soil condition in relation to moisture (Fig.3). There were no shifts observed during rise of moisture by 30% (insignificant change); during the increase in moisture by 60% (mild change), two phases were observed, caused by destroying the structural robustness of soil. The degradation of subsidence properties of paleosol horizons must unavoidably be taken into account in zones of impact of natural and additional loading.

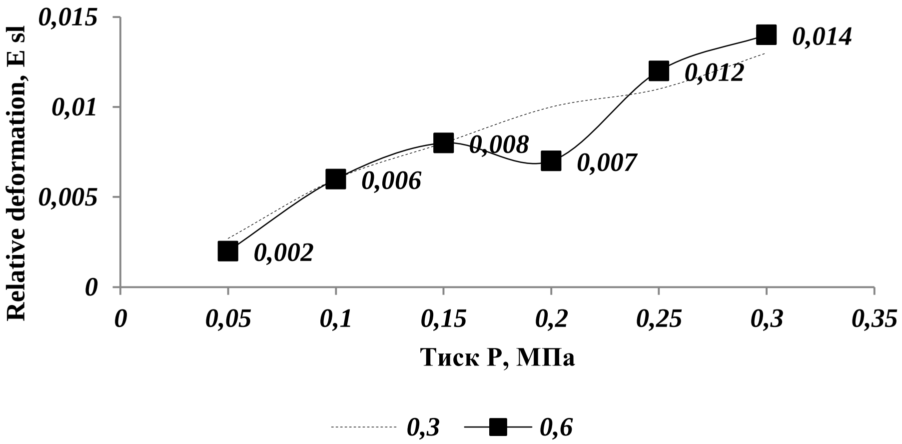

Fig. 3. Predicted values of subsidence degradation of paleosols during insignificant and mild change in the soil condition in relation to moisture

Conclusions. The results of analysis and prognosis of the degradation of subsidence properties of loess-like and paleosol horizons using methods of physical and mathematical modeling (correlational, regressive types of analysis, GMDH) indicates:

- The type of process in degradation of subsidence properties of subaerial loess-like and paleosol horizons is identified through genesis of the soil;
- The degradation of subsidence properties of loess-like soil is maximum in the area of pressures close to 0.1 MPa;
- Subsidence degradation in most cases is described as an uneven process consisting of two phases;
- The values of degradation of subsidence properties, which is followed by change in microaggregate composition, are significant and can affect the conditions of operation of the man-made structures.

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