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DYNAMICS OF LOESS MASS DEFORMATIONS DUE TO TECHNOGENIC LOAD

По результатам анализа энергетических и фильтрационных свойств техногенно нагруженного лессового массива определен интервал глубин, и геологические слои, характеризующиеся наиболее интенсивным развитием деформационных и суффозионных процессов. Приведенная методика оценки устойчивости массива, позволяет прогнозировать поведение склона с учетом нарушения его сплошности, произошедшего вследствие суффозионных процессов. Дана количественная оценка момента перехода массива в неустойчивое состояние, а также связь фильтрационных процессов с формированием оползней течения.

За результатами аналізу енергетичних і фільтраційних властивостей техногенно навантаженого льосового масиву визначені інтервал глибин та геологічні шари, що характеризуються найбільш інтенсивним розвитком деформаційних та суфозійних процесів. Наведена методика оцінки стійкості масиву дозволяє прогнозувати поведінку схилу з врахуванням порушення його цілісності внаслідок суфозійних процесів. Наведена кількісна оцінка моменту переходу масиву в нестійкий стан, а також зв'язок фільтраційних процесів з формуванням зсувів течії.

Analysis of energetic and filtration properties of loess with technogenic loads helps determine depth interval and geological layers characterized by maximum development of deformation processes and suffusion ones. Mass stability evaluation technique shown in the paper helps predict a slope behaviour involving its discontinuity as a result of suffusion processes. Moment of a mass transition into unstable condition is estimated quantitatively as well dependence of filtration processe on stream landslides formation.

Introduction. Today technogenic load of soils activates processes factoring into instability of buildings and structures. Right-bank area of Dnipropetrovsk is mainly located within underflooded loess. Their behaviour forecast is especially important in the process of construction of buildings and monitoring of the constructed ones [1]. Papers [2, 3] study innovative approach to the mechanisms of loess slopes behaviour as well as determine spatial regularities of changes of filtration and stability properties of soils in time with the help of triaxial compression. The results allow formulating the idea of quantitative character of hydrodynamic mode and its change if landslides occur. Moreover definite dependences of loess filtration parameters on deformations within various parts of landslide body were determined [3]. However, there is no generalized notion of the dynamics of mass deformations in terms of a real object.

Statements of the research. It is possible to forecast efficiently loess behaviour with the help of previously determined filtration dependences in loess as well as simulation of the processes of soil structure transformation into absolutely new one with the changes in geomechanical parameters. Thus, the research aim is to estimate deformations in loess in terms of slope mass with technogenic load as well as qualitative characteristics of the mass transformation into unstable one.

Material and the research results. Housing complex (h/c) to be simulated is within right-bank terraced slope of the Dnieper river-valley. It involves two residential section (eleven-storey and fifteen-storey) and parking. Its foundation down to 43.0 m depth is a complex of interlayer loess sandy loams and loam soils being bottomed by sandstones and rocky material. Thickness of subsiding soils is more than 31 m. Underground waters are represented as water-table aquifer lying at the depth of 31.4-32.0 m. Technogenic level is available fill-up ground at the depth of 5.1 m.

Municipal and accidental release from water-supplying communications violates humidity condition of aeration area. As a result, physical properties of soils, elasticity, and rigidity experience sharp changes.

Inverse problem was solving to form compete retrospective dynamics as for development of a mass watering phases and qualitative evaluation of their formation basic factors. To do that, numerical model of soil mass has been developed; the model is finite and element approximation of considered area of housing complex built-up area composed according to experimental results.

The model dimensions depend upon minimization of its contours effect on simulated area stress and strain state covering territory of 80 m where thickness of earth cover is 42 m. Network of triangular elements divides the cover according to the mass geological and lithological structure in a line of cross-sectional axis where maximum deformations of constructions is registered. Spatial certainty of modeled area was provided with zero relocations setting within the model side boundaries as well as along its floor edge corresponding to sand base. Records inform that residential sections are erected on 20 to 27 m friction piles with enlarged base. Monolithic substructure which load is equivalent to pile footing effect has been set in the model. Force interaction among the model elements was provided with gravity resulting from weight of earth cover and structures.

Generically, numerical model is represented by geotechnical elements (GTE) of nine types including zones of technogenic watering (Fig. 1).

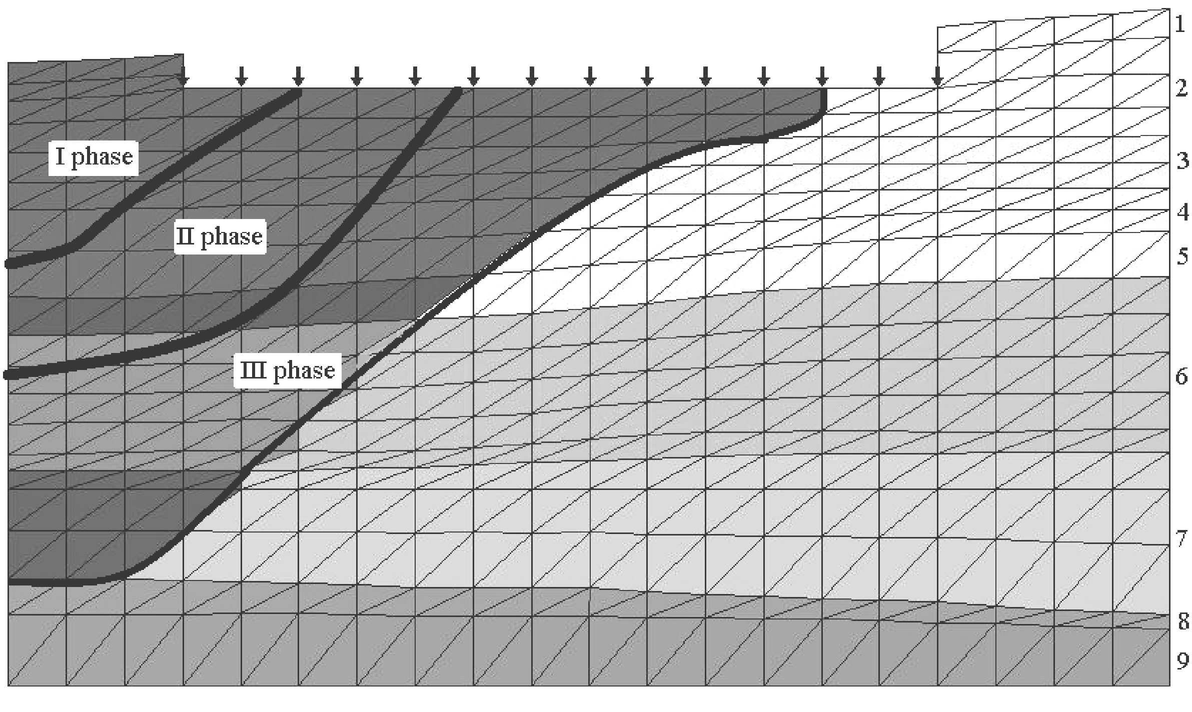

Fig. 1. Geologic profile in finite and element implementation with technogenic watering phases (I-III are phases of loess watering): 1- fill-up grounds; 2 – 7 - Upper-Quaternary deposits of loess association; 8, 9 - Lower- Quaternary alluvial quartz sands

It is reasonable to divide technogenic watering of loess into three phases. Fig. 1 demonstrates terminal positions of soil watering phases depending upon during intensive water loss in the period which came before water pipelines replacement.

Soil mass stability was evaluated according to a character of plastic deformation zones development.

Analysis of rock mass stress and strain state in the line of landslide dangerous shows that flooded soils at the bottom of loess mass are in plastic flow (beds 4 to 7). Shear deformation development is mostly typical within a zone of basic watering as well as its front boundaries. Development of faulting at the edge of skyline corresponds to rupture formation. Activation of buildings settlement is registered in the process of simultaneous frontal and subvertical technogenic watering of loess.

Water-saturated ground hardening occurring after water pipelines replacement fundamentally improves a picture; however, landslide deformations continue within settlements formed.

To analyze spatial and time changes in loess mass characteristics, settlement acceleration curves were constructed according to wall marks and registration marks (Figs. 2 and 3) as dynamics of registration marks settlement directly depends on a mass watering mode. Acceleration was involved to evaluate effect of changes in temperature conditions and moisture conditions (as a rule, settlement values and settlement rates are evaluated).

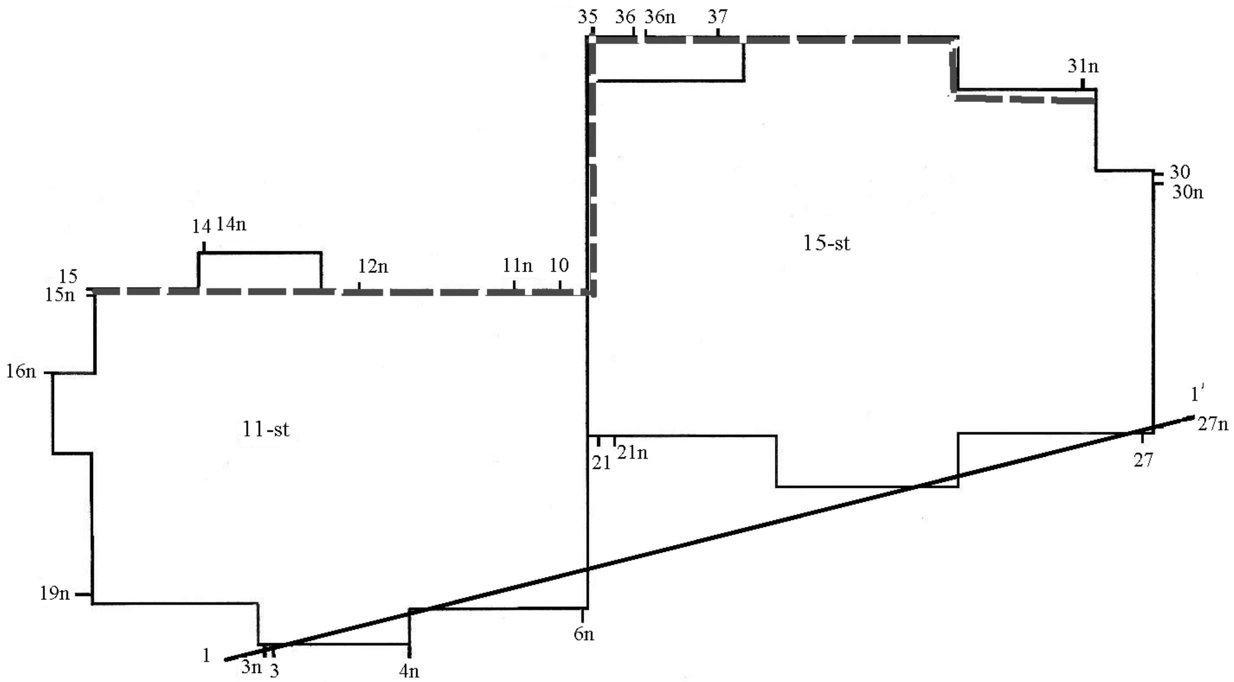

Fig. 2. Plan for registration marks setting at the territory of h/c: 1-1– a line of geotechnical profile; 2 ------ a zone of maximum settlements; 3n-37n –are numbers of registration marks with instrumental measurements of settlements

Direct dependence is observed between records and seasonal factors. In this graph seasonable activation of temporal acceleration changes in h/c buildings settlement are shown as transparent squares (Fig. 3). Deformation peaks belong to autumn-winter (end of November – beginning of February). Analysis of weather conditions explains that relatively warm December and beginning of January with precipitations (mainly rains) as well as active snow-melting coincides with deformation process activation.

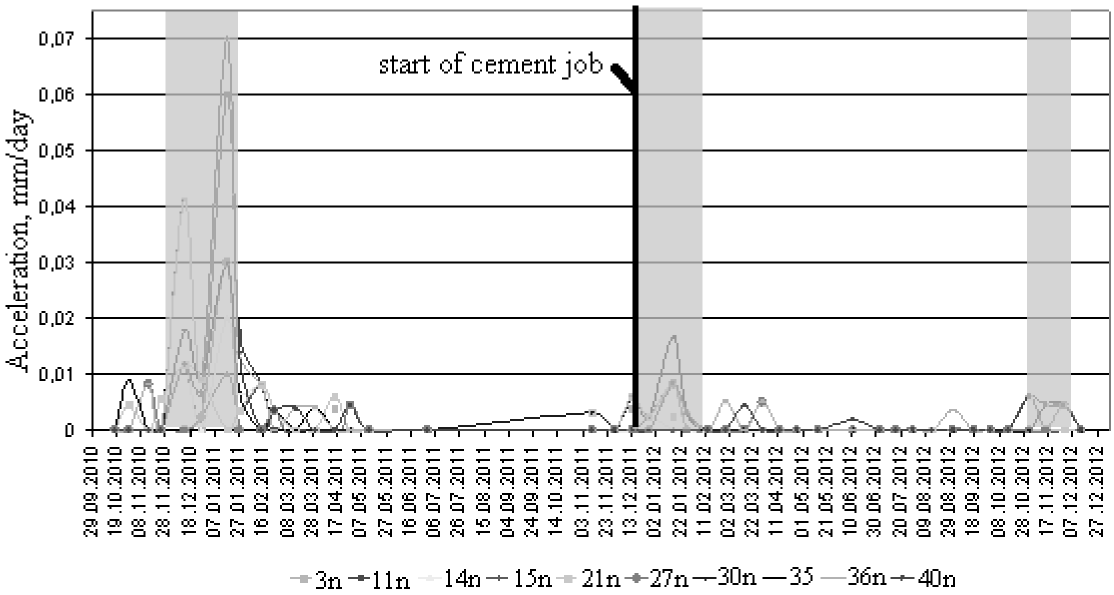

Fig. 3. Temporal changes in registration marks settlement

Variant of high-pressure cementation is proposed as engineering measure to prevent further deformation of housing complex. “Up-down” injection [4] took place through boreholes. Fig.3 shows that settlement damping phase corresponds to engineer measures as for water-supplying communications renewal. However, final settlement stabilization is not available. Experimental stage of injection cementation was followed by increased values of settlement acceleration which coincided with seasonable peak.

While cementing experimental site demonstrated excessive consumption (almost 40%) of liquid cement to compare with project-planned one; in this context project pressure could not be achieved. Following stages of geological prospecting within experimental site showed subvertical and vertical fractures mainly in 4 and 5 engineering geological elements which obviously resulted in liquid cement absorption. Data concerning fractures and cavities formed in the ground being probably a result of filtration and vertical displacements in the process of slope loading were also confirmed while inspecting communication wells in the neighbourhood of h/c. Moreover, ground cavities as well as ground accumulations being a result of suffusion processes were registered.

Research [3] determines qualitative characteristics of removed material in loess sandy clays under similar filtration conditions. Technique [2] involving structural links in loess ground helps develop a field of physical gradients of vertical slope subsection (Fig. 4). It takes into account three types of energy - loess underconsolidation, gravitation position, and deformations. Crossing of deformation gradient isolines and isolines of total potential energy in loess mass reflects position of critical surfaces inside the ground. Generally the model shows mass condition after development of the area of loess technogenic humidifying. Prognostic deformation areas in slope body with their quantitative characteristics according to activation potential values (total of full energy gradients and gradients of loess finite elements) are singled out on normals.

To compare with standard evaluation schemes as for slope mass stability we involve loess specificity in the form of potential field which interpretation makes it possible to define prognostic areas of dangerous deformation processes (Fig. 4).

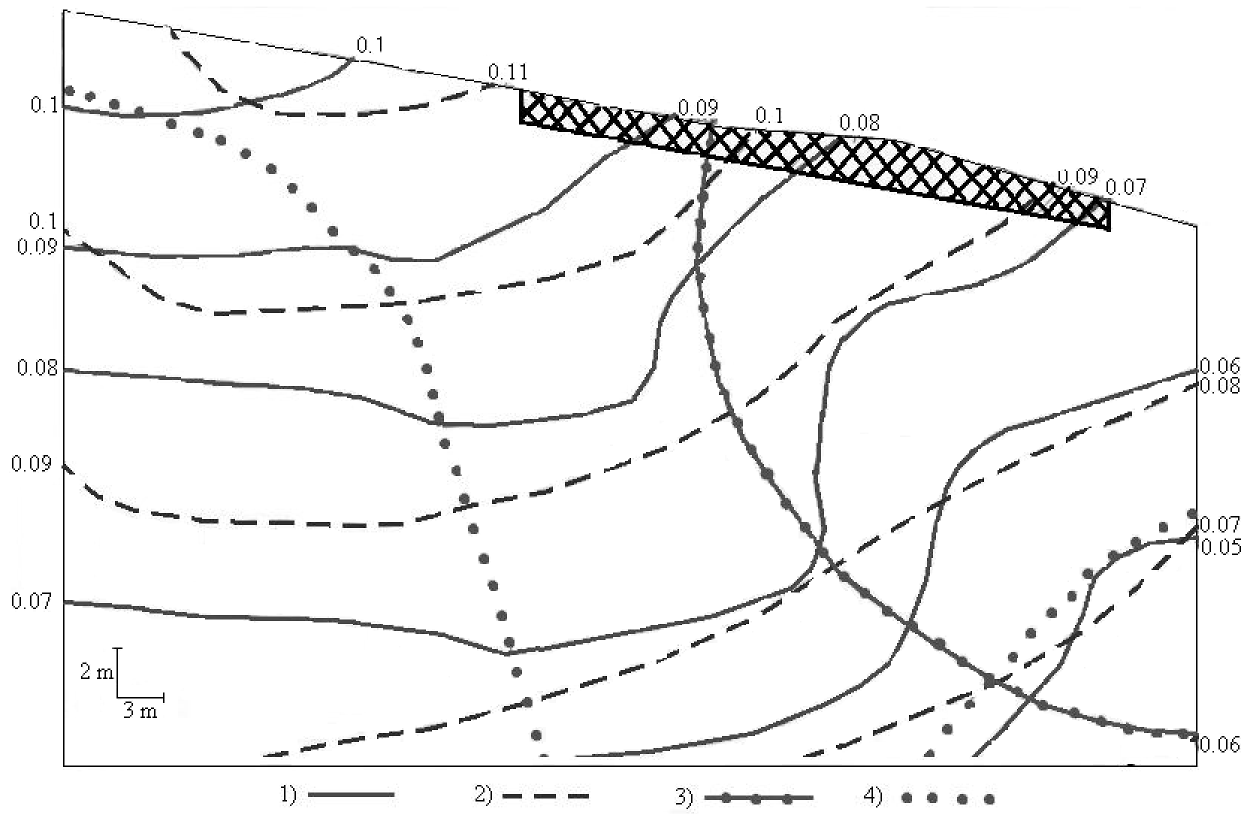

Fig. 4. Isolines of: 1- total slope energy; 2 – slope activation potential gradient; 3- prognostic slipping surface; 4 – boundary of technogenic humidifying

The simulation took into account three areas of slope humidifying. Data on fractures and cavities in the mass which were formed in the ground due to technogenic filtration and vertical displacements of a slope were taken into account in the form of areas with adequate values of rock strength properties. The most dangerous areas are within EGE 4 as well as in GTE 5 and 6. Values of slope activation potential within the areas vary within 0.07-0.08. Comparison with similar simulation data as for the landslide within Topol residential area where activation potential under landslide process is about 0.08-0.09 allows singling out these values as critical range.

Isolines of the mass energy gradients have strongly marked extremums in zones of peak deformations. Boundary value of activation potential gradient for 0.08-0.09 range of activation potentials is 0.0012. At the value, landslide processes become active in loess mass (Fig. 5).

The dependence corresponds to near-slope loess complex area being confirmed by data on determined inversion of loess filtration loess anisotropy to compare with its natural behavior provoked by technogenic changes in ground masses [3]. Erosion processes cannot be formed in terms of vertical filtration; if filtration takes place in a parallel with bedding then suffusion transforms into erosion to be confirmed by practice and actual formation of stream landslides. In terms of certain loads on loess, suffusion transforms into erosion wash with previous phase of hydraulically inert cavities occurrence. Comparing results of loess filtration tests with simulation results in terms of considered object shows that formation of erosion washes and cavities in 4-6 GTE results in maximum deformations.

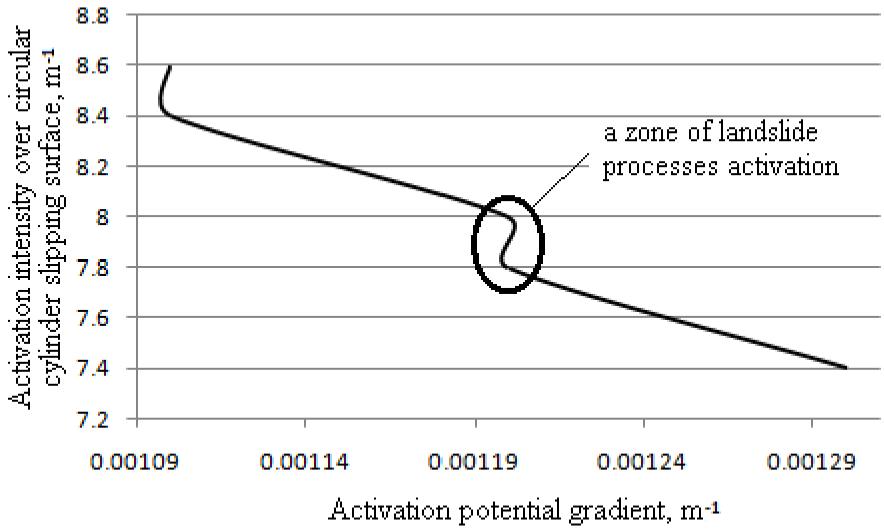

Fig. 5. Dependence of activation potential gradient on activation intensity over circular cylinder slipping surface in terms of 0.08–0.09 activation potential boundary values

Conclusions. Analysis of energetic and filtration properties of loess with technogenic loads helps determine depth interval and geological layers characterized by maximum development of deformation processes and suffusion ones. Mass stability evaluation technique shown in the paper helps predict a slope behaviour involving its discontinuity as a result of suffusion processes. Qualitative characteristics of landslide process activation are singled out basing upon mass activation potential gradient. Dependence of landslide process activation moment on activation intensity over circular cylinder slipping surfaceis determined. Moment of a mass transition into unstable condition is estimated quantitatively as well dependence of filtration processe on stream landslides formation.

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