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Assessment of Potential Environmental Risks from Saline Soils Subsidence

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Abstract. The nature and causes of soil subsidence in the areas of liquidated mining and chemical companies of the Carpathians are analyzed. Based on calculation results, was obtained dependences of salts concentration in the liquid, and the specific content of salt through the thickness of soil over time in cases of the dispersed and film salinity.

1. Introduction

Environmental safety of regions is one of the major problems in modern society. The deterioration of the ecological state of the environment and the worsening health of the population living in these areas determines the need to study environmental hazards and risks.

The problem of exploration and development of large land areas occupies a significant place in today's social conditions. High competition, high density of construction and insufficient land resources led to using structurally unstable soils for the construction. Saline soils often occupy large areas in technologically loaded regions.

The problem of preventing the destruction of civil and industrial buildings is one of the most important at the moment. When designing buildings in the area suffering from harmful effects of mining, we should take into account the current building regulations and international standards that are used in the construction of buildings [1].

Risk analysis should be an integral part of the procedure for adoption of design decisions and assessment of the impact of the projected activities on the environment at all stages of design. The main lines of further scientific research include elucidating the mechanism of modern morpho-dynamic processes, identifying the main natural and anthropogenic factors that contribute to their revitalization, city zoning by intensity, scope and nature of the process manifestation, a quantitative risk assessment for different types of objects, development of measures to reduce risks.

When choosing a construction site we must be sure that there are no deposits of potassium salts, there are deposits of non-economic reserves, the deposits are depleted, the process of deformation of the earth's surface was completed, the possibility of craters and cavities is excluded after stabilization of deformation, the excavation of pits is expected only after the completion of the amortization period of buildings [1].

The study of foreign experience enables the prediction of stability of the foundations of buildings erected in saline areas. In the current economic situation, residential housing develops at super-quick pace. Reducing the number of suitable building land leads to the construction on structurally unstable soils, including saline [2-3].

2. Parameter calculation methods

Subsidence of clay soils is characterized by a number of indicators: subsidence limit, soil skeleton density on the verge of subsidence, the relative linear and volumetric subsidence. Soil subsidence is often determined by calculation, using the method of M.J. Denisov, whereby the volume of soil subsidence V is calculated by the formula:

$$V = \left(1 - \frac{\rho_d^b}{\rho_d^c}\right) \cdot 100, \quad (1)$$

where ρ_d^b is the moist soil skeleton moisture; ρ_d^c is the dry soil skeleton moisture.
or the method of E.M. Sergeyev, where by the volume of completely saturated soil subsidence is described by the equation

$$V = V_c \cdot \left(1 + \beta_V \cdot W\right), \quad (2)$$

where: V is the volume of soil at humidity W; V_c is the volume of dry soil; β_V is the coefficient of volume subsidence equal to a relative increase in volume when humidity changes by 1:

$$\beta_V = \frac{V_1 - V_2}{V_2 W_1 - V_1 W_2}, \quad (3)$$

where V_1 and V_2 is the volume of soil at humidity W_1 and W_2, respectively.
Subsidence limit of the soil can be calculated from the ratio:

$$W_s = \frac{e_s \rho}{\rho_s}, \quad (4)$$

where: e_s is the soil porosity ratio on the verge of sinking; ρ is the density of wet soil; ρ_s is the density of solid soil.

In present-day study of soil mechanics there is no rigorous mathematical formulation of the stress-strain state of the array of saturated saline soils, and the variation of this state considering the processes of mass exchange and mass transfer between the components of soil. This greatly impedes further development of calculation methods for the base, which consist of saline soils. Salts of different quantitative composition, which are present in the soil, affect the deformation parameters of soils. When saline soils get wet, the salts contained in them are dissolved and removed, and soil porosity increases accordingly. An increase in the porosity of saline soils with moisture in turn leads to suffusion subsidence [1,4].
Subsidence of a homogeneous soil layer in the direction of axis X is calculated by formula (5):

$$S(t) = \int_{h_1}^{h_2} \alpha_0 (\sigma - \overline{\sigma_0})^{v_0} \frac{\xi_0 - \xi(t)}{\xi_0} dx \quad (5)$$

where: h_1, h_2 is the upper and lower limit of suffusion subsidence, respectively; $\sigma = \gamma_0 x$ is the change of the sealing load into the depth under natural stress state, MPa; γ_0 is the specific weight of soil in water-saturated state, N/cm^3; α_0, ν_0 are the non-linear deformation parameters that are constant for a homogeneous layer of soil; $\xi(t)$ is the distribution function of the specific amount of salt in fractions of units; $\overline{\sigma_0}$ is the minimum pressure at which there is a suffusion of soil subsidence, MPa [4].

In general, the variation of the specific volume of soluble salts in the soil depending on depth and time is described by the system of equations (6):

$$\begin{cases} Dm_0 \dfrac{\partial^2 C}{\partial x^2} - v\dfrac{\partial C}{\partial x} - \delta \dfrac{\partial \xi}{\partial t} = m_0 \dfrac{\partial C}{\partial t}; \\ \dfrac{\partial \xi}{\partial t} = -\dfrac{\gamma}{\delta}(C_m - C)\xi^k \end{cases} \tag{6}$$

where: D is the coefficient of convective diffusion, cm^2/s; C is the concentration of salts in the liquid, g/cm^3; ξ is the specific volume of salts in the soil, in fractions of units. C_m is the concentration of water saturation with salts of a given composition, g/cm^3; γ is the generalized coefficient of salt output, s^{-1}; m_0 is the soil porosity; v is the groundwater filtration rate, cm/s; δ is the density of salt, g/cm^3; k is the salinization coefficient. In the system of equations (6), k accepts values 0; 0.5; 1.0. At $k = 0$, we obtain a case of the film salinization of soil; at $k = 0.5$ or $k = 1.0$, we obtain a case of the volume (disperse) salinization of soil [5].

Let us consider the mathematical model of calculating the concentration of salts in the filtered liquid, and the model of calculating changes in the specific amount of salt contained in saline soils, and the suffusion subsidence caused. To solve this problem, system (6) is used with the following initial and boundary conditions (7):

$$\begin{cases} C(\bar{x},0) = C_H \\ \xi(\bar{x},0) = \xi_0 \end{cases}, \quad \begin{cases} \dfrac{\partial C(0,t)}{\partial x} = \dfrac{v}{m_0 D}(C(0,t) - C_0) \\ \dfrac{\partial C(l,t)}{\partial x} = 0 \end{cases} \tag{7}$$

where: is the even distribution of salt concentration in the liquid at the initial time through the thickness of soil, g/cm^3; C_0 is the concentration of salts in the initial section of soil, g/cm^3; ξ_0 is the even distribution of specific volume of salts in the soil at the initial time, in fractions of units; l is the soil thickness, cm [6].

Let us solve system of equations (6) with the initial and boundary conditions (7) using the finite difference method. Let us consider system (6) at $k = 0$ and v = const. This is a case of the film salinization of soil. This problem is reduced to solving a system of differential equations:

$$\begin{cases} \dfrac{\partial C}{\partial \bar{t}} = \dfrac{1}{Pe}\dfrac{\partial^2 C}{\partial \bar{x}} - \dfrac{\partial C}{\partial \bar{x}} + N(C_m - C) \\ \dfrac{\partial \xi}{\partial \bar{t}} = -\dfrac{1}{\delta}N(C_m - C) \end{cases} \tag{8}$$

with the initial and boundary conditions (9),

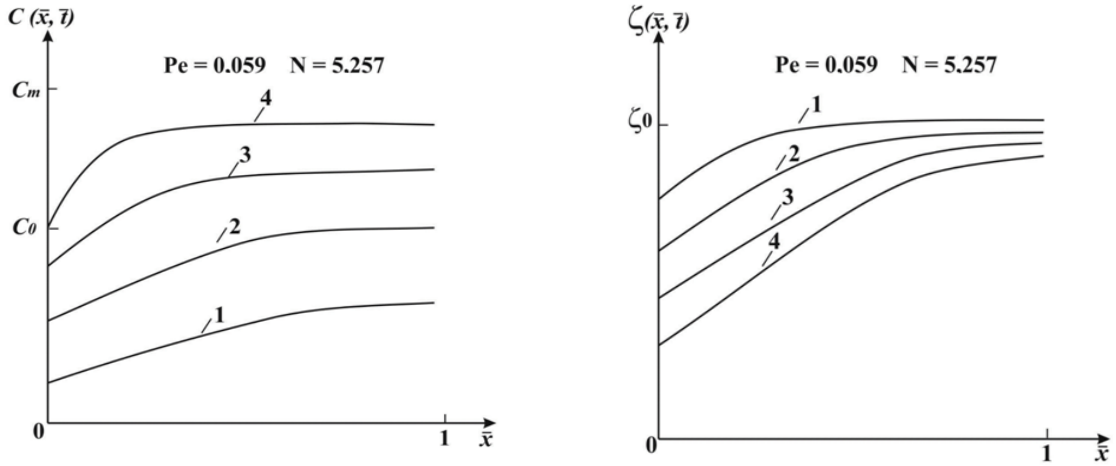
$$\begin{cases} C(\bar{x},0) = C_H \\ \xi(\bar{x},0) = \xi_0 \end{cases}, \quad \begin{cases} \dfrac{\partial C(0,\bar{t})}{\partial \bar{x}} = Pe(C(0,\bar{t}) - C_0) \\ \dfrac{\partial C(l,\bar{t})}{\partial \bar{x}} = 0 \end{cases} \tag{9}$$

where: $\bar{x}=\frac{x}{l}$ is the dimensionless coordinate; $\bar{t}=\frac{\nu \cdot t}{m_0 l}$ is the dimentionless time; $Pe=\frac{\nu \cdot l}{m_0 D}$ is the Peclet number; $N=\frac{m_0 \gamma \cdot l}{\nu}$ is the dissolution criterion.

Thus, problem (8)-(9) will depend only on two dimensionless criteria *Pe* and *N*.

3. Main results and their discussion

During calculations we used the following data: C_0 = 0.026 g/cm^3, C_H = 0.08 g/cm^3. Based on the calculation results we obtained dependences of salt concentration in the liquid (Fig. 1, a) and the specific content of salt through the thickness of soil over time (Fig. 1, b).



a b

Fig. 1. Dependence of salt concentration in the liquid - a, specific content of salt in the soil – b: 1 - $\bar{t}$ = 0.09; 2 - $\bar{t}$ = 0.27; 3 - $\bar{t}$ = 0.45; 4 - $\bar{t}$ = 0.63

Using the obtained distributions of function $\xi(x,t)$, we can determine the suffusion subsidence of soil in time for the natural stress state in case of the film and disperse salinization by formula (5). Calculations were made for two specific cases of the gypsified saline soil: *A* = 10 % (slightly gypsified saline soil) and *A* = 40 % (strongly gypsified saline soil). As is seen from the above dependencies, slightly gypsified soils provide less deformation compared to strongly gypsified soils. Similarly, strongly gypsified soils are characterized by relatively rapid stabilization of deformation, at which suffusion subsidence stops. These studies were conducted for saline gypsified soils of the gypsum-clay cap of Stebnyk deposits, which protects saline clay rocks from infiltration of freshwater [3, 7]. However, in general, the obtained dependences can be used for other types of saline soils as well. Analyzing spatio-temporal dynamics of the major hazardous ecology forming process, we can conclude that within Kalush industrial and urban agglomeration there are irreversible violation processes of the geological environment stability. Moreover, the catastrophic ecological and technological situation turns to the crisis of the national, and eventually, cross-border level.

Subsidence of soil surface over mining deposits, which are flooded, is largely due to the deterioration of their geomechanical stability due to surface leaching of pillars and diffusion wetting of rocks in the zone of contact with the insufficiently saturated solutions. Experience in the construction of various buildings proved that they are all in any way susceptible to deformations that occur as a result of the movement of soil particles [8].

The main causes of deformation can be divided into two groups:
- general causes associated with the peculiarities of the physical and mechanical properties of soils, which are the basis of the building foundation;
- partial causes associated with the peculiarities of construction works and operating mode.

A key danger is the subsidence of soil under the foundations of residential and civil buildings. One of the main factors is the type of the foundation soil [9,10]. In calculating the possible subsidence we used the methods described in building codes.

Let us consider possible subsidence of buildings located on saline soils. We assume that we have a uniform diffusive salinity within each layer of soil. Let us consider a soil array divided into ***i*** layers under the isotropy of physical and mechanical properties of each layer [12]. Then subsidence under full leaching will be:

Case 1: salinization was caused by one chemical compound (kainite) – i.e. monosalinization. In this case, subsidence under full leaching (Fig. 2a), excluding soil compaction due to flooding, will be:

$$H = \sum_{i=1}^{n} \frac{D_{sal_i} \cdot \rho_{soil\,i} \cdot h_i}{\rho_{sal}} \quad , \tag{10}$$

where: H is the subsidence of soil under full leaching of salts excluding flooding, (m); D_{sal} is the salt concentration in the i^{th} layer of soil, (fraction from 1) ; ρ_{soili} is the density of the i^{th} layer of soil, (kg/m^3); h_i is the height of the i^{th} layer of soil, (m); ρ_{sal} is the density of salt, (kg/m^3)

Case 2: salinization was caused by j chemical compounds – i.e. polysalinization. In this case, subsidence under full leaching excluding soil compaction due to flooding (Fig. 2, b) for each soil layer will be:

$$H = \sum_{i=1}^{n} \left(\sum_{j=1}^{m} \frac{D_{sal_{ij}}}{\rho_{sal\,j}} \right) \cdot \rho_{soil_i} \cdot h_i \ , \tag{11}$$

where: H is the subsidence of soil under full leaching of salts excluding flooding, (m); $D_{sal_{ij}}$ is the concentration of the j^{th} salt in the i^{th} layer of soil, (fraction from 1); ρ_{soili} is the density of the i^{th} layer of soil, (kg/m^3); h_i is the height of the i^{th} layer of soil, (m); $\rho_{sal\,j}$ is the density of j^{th} salt, (kg/m^3)

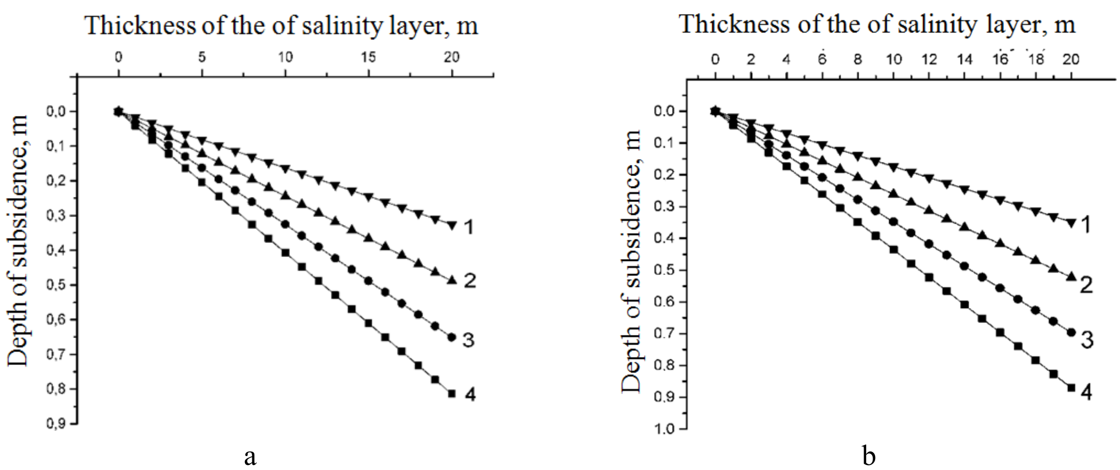


Fig. 2. Dependence of the depth of subsidence on the level and depth of salinity: a - in case of monosalinization; b - in case of polysalinization;
1 - $D_{sal} = 0.02$, 2 - $D_{sal} = 0.03$, 3 - $D_{sal} = 0.04$, 4 - $D_{sal} = 0.05$.

For polysalinization we considered soluble compounds most common in the territory in question. Low soluble compounds, and, therefore, low deformations in the leaching shall be neglected. Based on the analysis of the chemical composition of saline soils we identified key components of salinization: kainite, halite, carcallite, K_2SO_4, $MgSO_4$.

We divide salts into three types by their solubility in water:

I - $MgSO_4 + K_2SO_4$;
II - halite+ kainite;
III - carnallite.

We accept that the amount of the leached salts is directly proportionate to their solubility in water [11]. Then weighting coefficients will be: for I type salt 0.425; for II type salt 0.2; for III type salt 0.375, Fig. 3.

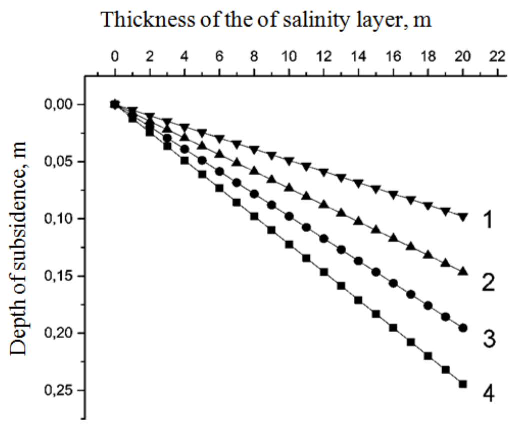


Fig. 3. Dependence of the depth of subsidence on the level and depth of salinity, taking into account weighting coefficients: 1 - $D_{sal} = 0.02$; 2 - $D_{sal} = 0.03$; 3 - $D_{sal} = 0.04$; 4 - $D_{sal} = 0.05$

Currently, there is no rigorous mathematical formulation of the problem of stress and strain condition in the area of water saturated saline soils. Therefore, it is necessary to improve the proposed model by taking into account soil subsidence as a result of flooding and compaction of soil particles.

It is also necessary to accumulate and organize theoretical and experimental data to create a database of weighting coefficients of the main salinization components to improve the quality of calculation of leaching processes with a view to a better prediction of suffusion subsidence of saline soils.

4. Conclusions

A simplified mathematical model of saline soils subsidence due to leaching in cases of mono- and polysalinity is proposed. The development of mathematical models with a view to making them universal is planned in the future. It is also planned to adapt calculations to the operating conditions of liquidated mining and chemical companies of the Carpathians.

Kinetic curves of suffusion subsidence are built for the disperse and film salinity, which will help predict and monitor subsidence of saline soils in technologically loaded areas. The relationship between the degree of salt dispersion and the rate of salt leaching is established, and the dissolution rate is shown to be proportional to the total area of the interface “salt-solvent”.

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