UDK 624.131.136.22

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QUALITATIVE RELATIONSHIPS OF WATER MIGRATION IN HIGHWAY EMBANKMENT CLAY SOILS

The influence on highway embankment clay soil continuous strength some factors: soil skeleton density after it's compaction in the embankment, embankment height, time factor (the number of days that embankment «rests» before it's service is analyzed. The methodology of physical water migration modeling by the highway embankment height through time changes research of clay loam moisture, placed in plastic tubes and compacted at water saturation factor $S_r = 0,85$ to soil skeleton density $\rho_d = 1,50 - 1,65$ g/cm^3 is developed and realized. The moisture changes graphs of light silt loam at soil skeleton density for the tubes height for each given soil skeleton density and for each accepted time-lagged is plotting in the article. New experimental relationships of compacted highway embankment clay loam moisture conditions and it's time-lagged till service start, which it's expedient to consider at optimal clay soils compaction criteria improving, which provide highway embankment long-term strength are established.

Keywords: *highway embankment, long-term strength, water migration, compacted clay loam, soil skeleton density, embankment height, time-lagged.*

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КІЛЬКІСНІ ЗАКОНОМІРНОСТІ МІГРАЦІЇ ВОДИ В ГЛИНИСТИХ ДОРОЖНІХ НАСИПАХ

Проаналізовано вплив на тривалу міцність глинистого ґрунту в дорожньому насипу деяких факторів: щільності скелета ґрунту після його укочування в насипу; висоти насипу; часу (кількості діб, які насип «відпочиває» до експлуатації). Розроблено й реалізовано методику фізичного моделювання міграції води за висотою дорожнього насипу шляхом досліджень змін у часі вологості пилуватих суглинків, вміщених у пластмасові труби й ущільнених за коефіцієнта водонасичення $S_r = 0,85$ до щільності скелета ґрунту $\rho_d = 1,50 - 1,65$ г/см^3. Побудовано графіки зміни вологості ущільненого суглинку легкого пилуватого за висотою труби при заданій щільності скелета ґрунту, вологості та часу його витримки до початку еклпуатації. Установлено нові експериментальні залежності вологісного режиму ущільненого суглинку дорожнього насипу від часу його витримки до початку експлуатації, висоти та щільності скелета ґрунту, які доцільно враховувати при вдосконаленні оптимальних критеріїв ущільнення глинистих ґрунтів, за яких забезпечується тривала міцність дорожнього насипу.

Ключові слова: *дорожній насип, тривала міцність, міграція води, ущільнений суглинок, щільність скелета ґрунту, висота насипу, час витримки.*

Introduction. For the long-term strength of road embankment it’s necessary not only to achieve maximum multilayer consolidation values of his soil skeleton density and strength, but also to save them during normative operational time.

Monitoring in 23 regions of Ukraine established that the majority of abnormal deformations (52,2%) recorded in highway embankments higher than 21 m. The average percentage of these embankments deformations – 31,1%. The main type of abnormal deformations (70%) – washouts slopes of embankments, earth-bank and road shoulder breaks [1]. Figure 1a shows a typical case of soil liquefaction. Based on current knowledge, the suspected causes are rain and/or wind and/or grain redistribution within the soil due to high local hydraulic gradients. 70% of the in-cidents occurred during the months of January to March, that is at low temperatures and with ground frost [2]. Figure 1b describe longitudinal cracks near the edge of pavement. Reason – tensile stresses induced by flexion of the pavement during settlements caused by the dry season leads to the develop-ment of longitudinal cracks. During the dry season there is a drop off in moisture content of the soil in the shoulders of the pavement structure. The consequence of this reduction in moisture is a settlement in the shoulders that does not take place in the centre of the pavement where the moisture of the soil remains stable thorough the year [3 – 5].

a)

b)

Figure 1 – Deformations on the highways:
a – flow liquefaction at former open-pit mine Schlabendorf-Süd;
b – longitudinal cracks near the edge of pavement

That’s why one of significant problems of highway embankment erection is their long-term strength ensuring, when during normative operational time the values of soil mechanical characteristics, obtained after compaction, have been saved.

Review of recent sources of research and publications. It was established earlier by author [6, 7] that for continuous highway embankment service it’s necessary not only to achieve maximum values of soil skeleton density and strength, but also to save them during continuous service time.

The possibility and effectiveness of soil compaction is determined by the method of standard compaction [8]. Herewith the dependency graph of moisture w from soil skeleton density ρ_d is plotting (Fig. 2) and is determining maximum soil skeleton density $\rho_{d\,max}$, which achieves at certain moisture, called optimum W_{opt} [9 – 11].

Optimum clay soils moisture in the absence of direct data definition is recommended to determine:

– at the compaction by roller

$$W_{opt} = W_P; \qquad (1)$$

– at the compaction by rammer

$$W_{opt} = W_P - (0{,}01 - 0{,}03), \qquad (2)$$

whereat W_P – plastic limit.

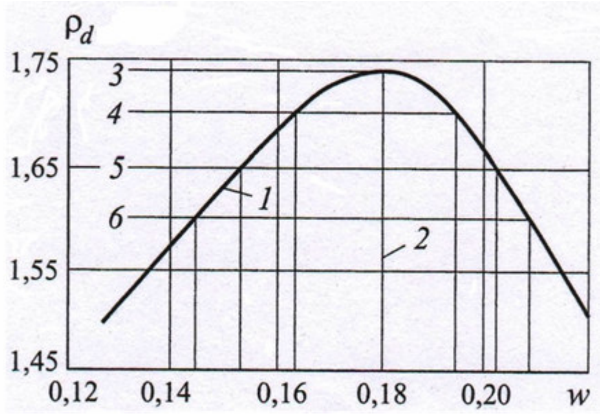

**Figure 2 – The dependency of soil skeleton density from moisture:
1 – soil compaction curve; 2 – optimum moisture;
3 – maximum soil skeleton density**

Parts of the common problems that earlier unsolved. Now both in Ukraine and in the world at the highway embankments erection it is normalized soil skeleton density, which is determined for each type of soil in the laboratory by Proctor test or its modification [1, 8, 10, 11]. The problem lies in the fact that parameters for long-term strength saving of compacted soil over time not considered. On the condition of compacted soil over time significantly affects moisture at which it compacted, and the proportion of water certain types in this soil [12, 13].

If the soil was compacted at moisture less than maximum molecular moisture capacity W_{con}, the electric potential of solids surface isn't used, and they are able to increase the thickness of unfree water film to the maximum possible value with additional soil moistening during massif operation. Unfree water thickness film increasing leads to increase of compacted soil initial volume and construction deformation [12, 14].

If the soil was compacted at moisture, which significantly exceeds maximum molecular moisture capacity then electric potential of solids surface is fully used, system has a neutral charge, and the thickness of unfree water film – maximum value [11, 14]. The presence of significant free water amount leads to the fact that water over time under gravity, soil gravity and external loads expels from the pores. It helps to addit soil compaction due to more compact particles placement. Accordingly, the soil strength increases, and there are non-uniform deformation [12, 15].

So, the most auspicious condition for the long-term soil embankment strength and minimum deformation during its operation is to compact the soil to moisture close to maximum molecular moisture capacity.

Maximum molecular moisture capacity is approximately determine from the equation

$$W_{con} \approx W_p - 0{,}02\,. \tag{3}$$

Problem statement. On the the long-term strength parameters of highway embankment clay soils significantly affects a number of factors, which should be mentioned at it's erection and also it's moisture conditions:

– soils type, namely it's indicative characteristics: liquid limit W_L; plastic limit W_p; plastic index I_p;
– soil skeleton density after it's compaction in embankment ρ_d;
– the amount of unfree water at what the soil is compacted (soil moisture);
– embankment height;
– time factor (the number of days that embankment «rest» before it's service.

Author developed and realized the methodology of physical water migration modeling by the highway embankment height through time changes research of clay loams moisture, placed in plastic tubes and compacted at water saturation factor $S_r = 0{,}85$ to soil skeleton density $\rho_d = 1{,}50 - 1{,}65$ g/cm^3. Light silt loam was used ($W_L = 0{,}279$; $W_p = 0{,}191$; $I_p = 0{,}08$) in this work.

Main material and results. Soil skeleton density (or void volume ratio e) was accepted as a first changeable factor. Accordingly soil moisture at $S_r = 0{,}85$ in each experiments had changeable value:

– at soil skeleton density $\rho_d = 1{,}50$ g/cm^3 – $w = 0{,}250$;

– at $\rho_d = 1{,}55$ g/cm^3 – $w = 0{,}231$;

– at $\rho_d = 1{,}60$ g/cm^3 – $w = 0{,}214$;

– at $\rho_d = 1{,}65$ g/cm^3 – $w = 0{,}198$.

The fabricated tubes height was: 45; 90; 150; 210; 285 cm. At this rate the each tube link height was 15 cm. Research time-lagged of comacted soil was 60 and 120 days.

For the work realization it is used: weigher; hand sprinkler; 40 plastic tube links 50 mm (external diameter) × 150 mm (the height of each tube link); vertical frame; drainage channel; hand tamper; spatula. Inner tubes diameter was 46,4 mm. It was accepted in calculations of initial soil mass to fill certain tube volume.

Soil filling in the tubes is done stepwise to a height of 3 cm. Be designated by soil skeleton density and it's moisture, for the corresponding volume of soil nature moisture mass ($w_o = 0{,}132$) and moisture mass, what should be add to get given moisture w, at what water saturation factor value is $S_r = 0{,}85$ was calculated.

Appropriate soil mass for four variants are selected and weighed (Fig. 3, a). The soil was moistened to a given moisture w by hand sprinkler (Fig. 3, b) and mixed by spatula for the uniform moistening of research soil portion (Fig. 3, c). Then by portions it was moved in tubes and uniform compacted using hand tamper with certain marks by its height (Fig. 3, d) all time to thickness of 30 mm, and then tube link (150 mm) was connected to a total height (Fig. 3, e, f). These tubes with compacted soil layers were installed on a metal vertical frame. The lower tube ends was installed in drainage channel, filled with stone screening dust. Thus, free (gravity) water had opportunity migration for all height of soil in the tube, what imitate it's migration within the thickness of highway embankment. The top of all tubes with compacted soil layers was hermetically closed to avoid evaporation of water «up». On each tubes the dates of initial soil skeleton density ρ_d and defined moisture w was sticked down. Then tubes left on vertical frame alone, for, so-called «rest».

After given «rest» time all tubes were dismantled into separate links. From each of the link was selected at least two soil sample bottles, and by normative weight method the final (stabilized) moisture w_k of compacted clay soil for all tube height was determined.

By the results of laboratory studies of the factors influencing on water migration in the compacted clay soils thickness the moisture changes graphs of light silt loam at soil skeleton density for the tubes height for each given soil skeleton density and for each accepted time-lagged is plotting in the article.

Plotting graphs examples of compacted light silt loam moisture changes at soil skeleton density $\rho_d = 1{,}50$ g / cm^3 and moisture $w = 0{,}250$ is presented in Fig. 4, and at soil skeleton density $\rho_d = 1{,}65$ g / cm^3, moisture $w = 0{,}198$ – in Fig. 5. The tube height in these cases was 150 cm and the time-lagged was 65 days.

Plotting graphs examples of compacted light silt loam moisture changes by tube height of 0,9 m is presented in Fig. 6, and by tube height of 2,85 m, – in Fig. 7. Soil skeleton density in these cases was 1,55 g/cm^3, moisture $w = 0{,}231$ and the time-lagged was 60 days.

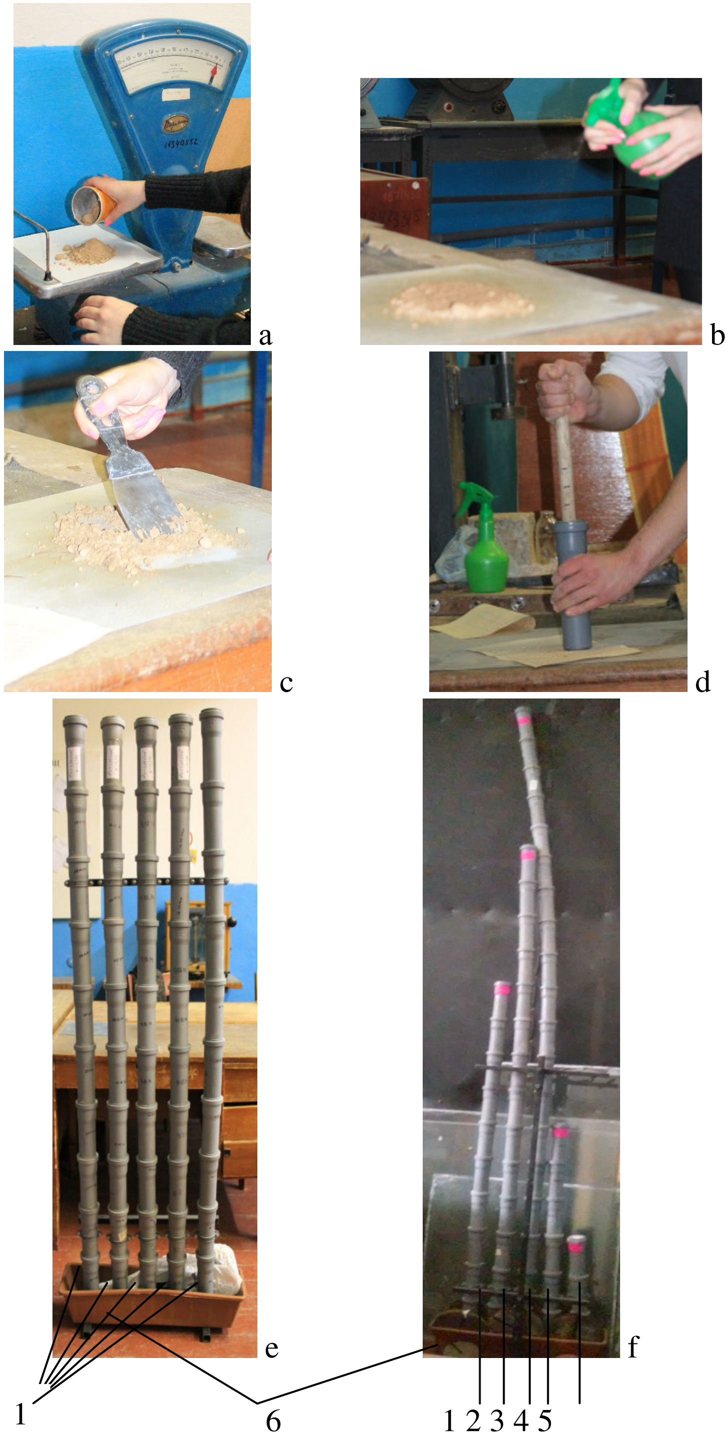

Figure 3 – Stages of compacted highway embankment clay loam moisture conditions laboratory studies:
a – weighting an appropriate research soil mass portion;
b – additional moistening of clay soil portion to a given value w**;**
c – research soil mixing for it's uniform moistening;
d – multilayer (3 cm) compaction of each loam portion;
e, f – erected to a common tube links height:
1 – 1,50 m; 2 – 2,10 m; 3 – 2,85 m; 4 – 0,9 m; 5 – 0,45 m;
6 – drainage channel

Plotting graphs examples of compacted light silt loam moisture changes after 74 days of the «rest» time is presented in Fig. 8 and at the «rest» time of 120 days – in Fig. 9. Soil skeleton density in these cases was 1,55 g/cm^3, moisture w = 0,231 and the tube height was 1,50 m.

Conclusions. So, by the way of physical water migration modeling through time changes research of clay loam moisture, compacted at water saturation factor S_r = 0,85 to soil skeleton density ρ_d = 1,50 – 1,65 g/cm^3 it is proved that:

– with highway embankment clay soil skeleton density increasing, it's moisture decreases;

– embankment height does not substantially affect on moisture conditions of compacted clay soils;

– time-lagged of compacted clay soils embankment influences on moisture migration in it, i.e the longer embankment «rests» before it's operation, the less it's moisture along all tube height (with «rest» time increasing from 74 to 120 days the loam moisture increased on 1,5 %).

In this case, however, the final clay soil moisture is close to the so-called maximum molecular moisture capacity. Its value depends mainly on indicative clay soil parameters and soil skeleton density in the embankment.

Thus, the new experimental relationships of compacted highway embankment clay loam moisture conditions from it's time-lagged till service start, embankment height and clay soil skeleton density which it is expedient to consider at optimal clay soils compaction criteria improving, which provide highway embankment long-term strength are received.

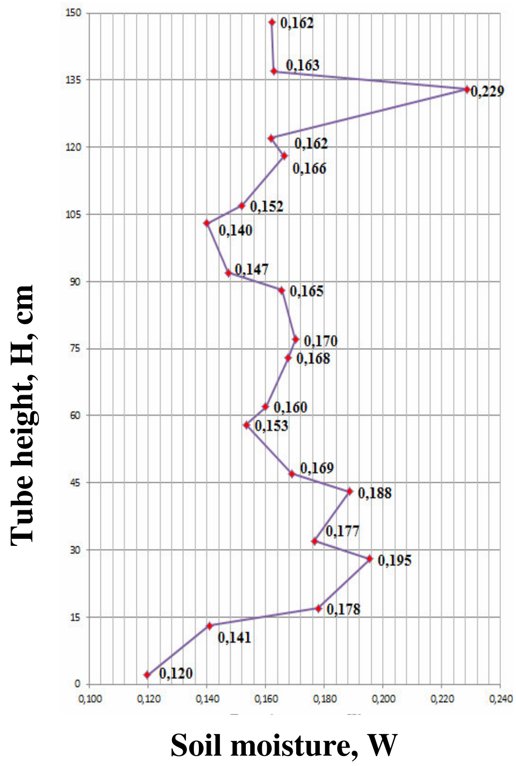

Figure 4 – Plot of compacted light silt loam moisture change at soil skeleton density ρ_d = 1,50 g/cm^3 and a tube height of 150 cm

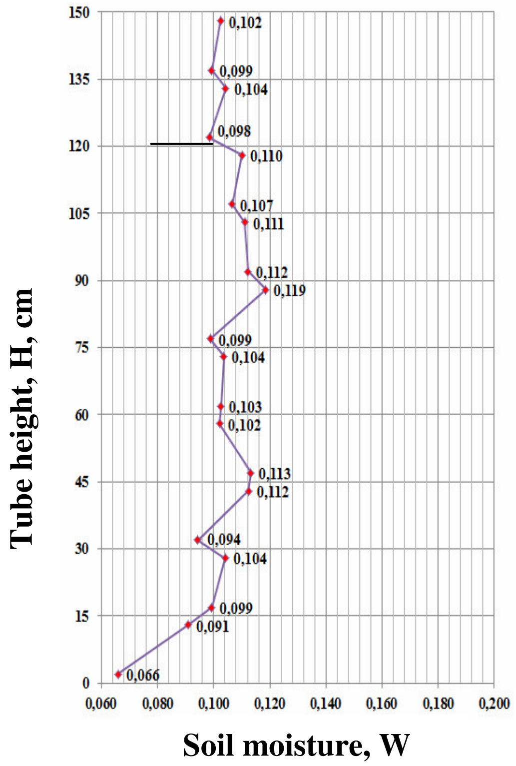

Figure 5 – Plot of compacted light silt loam moisture change at soil skeleton density ρ_d = 1,65 g/cm^3 and a tube height of 150 cm

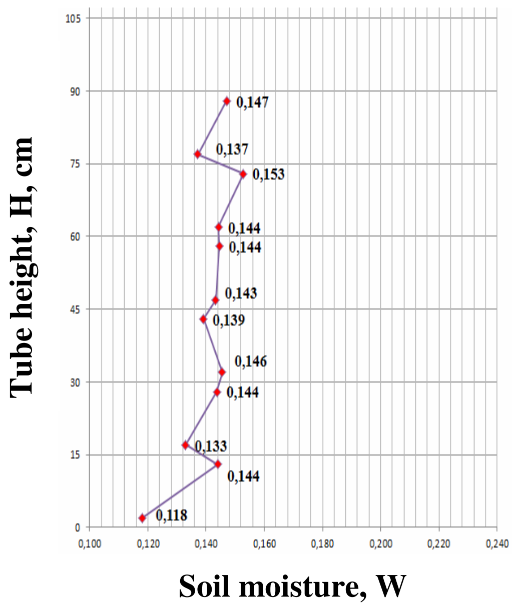

Figure 6 – Plot of compacted light silt loam moisture change at soil skeleton density ρ_d = 1,55 g/cm^3 and a tube height of 90 cm

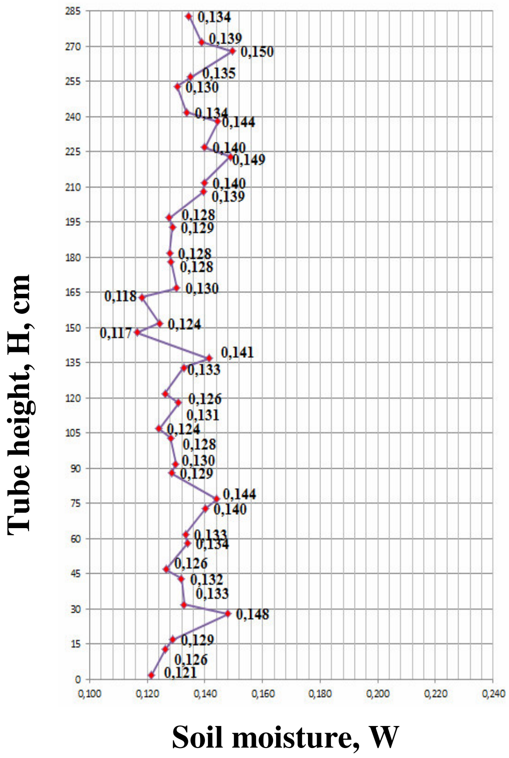

Figure 7 – Plot of compacted light silt loam moisture change at soil skeleton density ρ_d = 1,55 g/cm^3 and a tube height of 285 cm

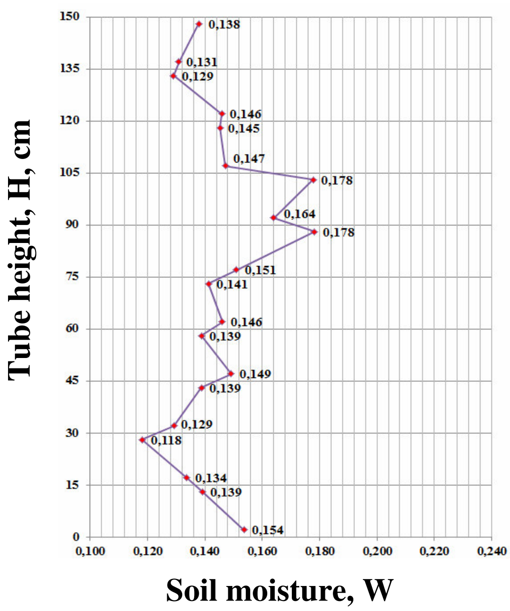

Figure 8 – Plot of compacted light silt loam moisture change at soil skeleton density ρ_d = 1,55 g/cm^3 and a tube height of 150 cm (time of the «rest» 74 days)

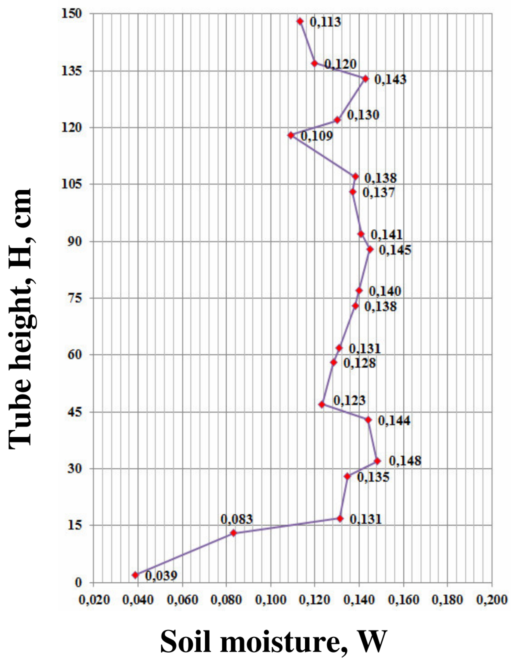

Figure 9 – Plot of compacted light silt loam moisture change at soil skeleton density ρ_d = 1,55 g/cm^3 and a tube height of 150 cm (time of the «rest» 120 days)

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Надійшла до редакції 04.04.2016