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***Vynnykov Yu.L.**, DSc, Professor*
ORCID 0000-0003-2164-9936 vynnykov@yandex.ru
***Lvovska T.V.**, PhD, Senior lecturer*
ORCID 0000-0002-4747-3353 tetyana.jasmine.lytvynenko@gmail.com
Poltava National Technical Yuri Kondratyuk University

MOISTURE CONDITIONS PATTERNS IN ROAD EMBANKMENT CLAY SOILS DEPTH

The article deals with optimal compaction criteria of road embankment soils improving, which provide their long-term strength. Physical experiment methodology for patterns establishment of water migration in subgrade embankment depth, in the capacity factors of what it is accepted: clay soil type (its number plasticity); moisture, at what the soil was compacted; soil skeleton density; embankment height; «rest» time after subgrade erection and before it's operation are developed and realized. By laboratory and field tests water migration patterns in compacted subgrade soils depth are established. As a result of statistical processing of laboratory and field research results, the empirical dependence of compacted clay soil stabilized moisture for their multilayer consolidation in relation to soil skeleton density and plasticity number values is obtained.

***Keywords**: road embankment clay soils, long-term strength, water migration, loam multilayer consolidation, maximum soil skeleton density, maximum molecular moisture capacity (maximum quantity of unfree water).*

***Винников Ю.Л.**, д.т.н., професор*
***Львовська Т.В.**, к.т.н., ст. викладач*
Полтавський національний технічний університет імені Юрія Кондратюка

ЗАКОНОМІРНОСТІ ВОЛОГІСНОГО РЕЖИМУ В ТОВЩІ ГЛИНИСТИХ ҐРУНТІВ ДОРОЖНІХ НАСИПІВ

Удосконалено оптимальні критерії ущільнення глинистих ґрунтів дорожнього насипу, за якими забезпечується їх тривала міцність. Розроблено та реалізовано методику фізичного експерименту зі встановлення закономірностей міграції води в товщі земляного полотна, фактори котрого: вид глинистого ґрунту (його число пластичності); вологість, при якій його ущільнювали; щільність скелету ґрунту в насипу; висота насипу; час «відпочинку» після зведення і до початку експлуатації земляного полотна. Шляхом лабораторних і польових дослідів установлено закономірності міграції води в товщі ущільнених ґрунтів земляного полотна.

***Ключові слова:** глинистий ґрунт дорожнього насипу, тривала міцність, міграція води, пошарово ущільнені суглинки, максимальна щільність скелету ґрунту, максимальна молекулярна вологоємність (максимальна кількість зв'язаної води).*

Introduction. When soil compacts due to high moisture, with a degree of saturation close to S_r = 1,0, soil dries and holds its sedimentation and therefore additional deformations. When soil compacts due to low moisture, it will be difficult to do the compaction, there is a little probability of desired soil skeleton density achieving, even with the modern mechanisms possibilities. Also national standards recommend to take plastic limit W_p,for optimum clay soils moisture content, at the compaction by roller, but this parameter is not related on how much unfree water the soil is actually containing [1 – 5]. That is why for subgrade erection it is important to have long-term strength ensuring, i. e., when during normative operational time the values of soil mechanical characteristics, obtained after compaction, have been saved and excess soils deformation does not appear.

Recent sources analysis of research and publications. Now both in Ukraine and in the world at the highway embankments erection it is normalized soil skeleton density, determined for each type of soil in the laboratory by Proctor test or its modification [5, 6]. However, the problem is that domestic regulations prescribe optimal parameters of compacted clay soil (maximum soil skeleton density ρ_{dmax} and optimum moisture content W_{opt}), based on the obtained values of laboratory conditions for a particular soil type and dynamic load characteristics without actual mechanisms characteristics [6 – 9].

The disadvantages of the soil subgrade compaction methods are: the necessity to «bind» the soil compaction curve to specific compaction mechanism certain parameters; sufficiently wide boundaries of optimum soil moisture; some subjectivity in soil plastic limit determining etc. So, the most common today concept in road soil compaction construction solves is mainly the technological side of problem – the maximum soil skeleton density at fewest mechanism passage according to [6, 8].

Identification of general problem parts unsolved before. For the reliable subgrade operation it is necessary not only to achieve maximum multilayer consolidation values of its soil skeleton density and soil strength, but also to save them during normative time. On the embankment soils condition over time moisture affects significantly where the compaction was done and the particular water type split in compacted soil [10 – 13]. But the next factors as for quantitative impact on moisture conditions patterns in road embankment clay soils depth still have not been researched: soil skeleton density; compacted embankment height; the number of days compacted clay embankment «rests» after its erection, and before the operation [10, 12].

In soil mechanics, minimum stress where soil sample is destroyed due to aeonic span of time, accepted as long-term strength limit. Stress where the soil sample is destroyed due to certain period after load imposing as a result of unchangeable soil flow and advance flow of ground, corresponds to the soil long-term strength. So the theory considers the most favorable conditions for the subgrade clay soils long-term strength ensuring and minimum ground distortion during specified time operation is to compact the soil in layers at moisture, close to maximum molecular moisture capacity [8, 10 – 13].

Basic material and results. For new optimal compaction criteria of road embankment soils substantiation where subgrade clay soil long-term strength is ensured, the new physical experiment methodology for water migration patterns establishment in subgrade embankment depth is already developed and described in the works [10 – 13].

As a result of statistical processing by least squares method of research data it is found that the decreasing of stabilized moisture value w_k of compacted heavy silty loam (research soil № 1) depending on the soil skeleton density growth within the experimental range ρ_d = 1,50 – 1,65 g/cm^3 it is most correctly to describe by logarithmic function of the form [13]

$$w_k = a + b\ln\left(\frac{\rho_d}{\rho_{d0}}\right) \quad , \qquad (1)$$

where is ρ_{d0} = 1 g/cm^3;

empirical coefficient is: a = 0,358; b = - 0,384.

At this multiple correlation coefficient r and variation coefficient v values is: r = 0,997; v = 0,008, that indicates close relationship between the experimental data and about the correctness of their approximation by the logarithmic function [10, 13].

Analogous logarithmic dependence is obtained also for stabilized moisture value w_k of compacted light silty loam (research soil № 2). Empirical coefficient of equation (1) is a = 0,362; b = - 0,494.

At this multiple correlation coefficient r and variation coefficient v values is: r = 0,998; v = 0,0115, that indicates close relationship between the experimental data and about correctness of their approximation by the logarithmic function [13].

Comparing by data [11 – 13] of the final average soil moisture values w_k of compacted loams after two months «rest» with initial moisture values w of this soil it can be stated, that:

– final average soil moisture value w_k of compacted loams is compared with initial moisture w, where the clay soil was compacted and decreased for all soil skeleton density value ρ_d almost for all tube height except its upper link, where soil moisture approached to the value w_{sat}, that corresponds to degree of saturation $S_r \approx 1,0$ by raising capillary moisture. Soil moisture in lower tube link decreased to w = 0,10 – 0,12 and light silty loam moisture to w = 0,08 due to evaporation of free water;

– final moisture value w_k of compacted subgrade loams within experimental range ρ_d = 1,50 – 1,65 g/cm^3 decreases by dependence, close to logarithmic with soil skeleton value increasing, that is explained by the fact that with ρ_d increasing due to the fact of ρ_d increasing film thickness of unfree water decreases and besides, the coefficient of permeability also decreases, that reduces to moisture speed redistribution;

– stabilized soil moisture w_k in all cases is less than soil plasticity number W_p and approach to this maximum molecular moisture capacity *is* w_{mm});

– moisture decreasing of initial w where the soil was compacted, within highway embankment in practice causes its additional settlement.

The average values of compacted light silt loam stabilized moisture w_k determining dependence on pipe height at soil skeleton density value ρ_d = 1,55 g/cm^3 are:

at pipe height of 0,45 m – w_k = 0,138;

0,9 m – w_k = 0,141;

1,50 m – w_k = 0,129;

2,10 m – w_k = 0,129

and at 2,85 m – w_k = 0,133.

Moisture plots changes analysis of compacted loam height wise the pipe of 0,45 m, 0,9 m, 1,50 m, 2,10 m and 2,85 m shows, that the compacted clay soil height as a part of subgrade did not significantly affect its moisture condition.

From the moisture plots changes analysis of light loam height wise, the embankment (pipe) is compacted at moisture w = 0,231 to soil skeleton density ρ_d = 1,55 g/cm^3, after 74, 120 and 180 days of the «rest» in particular, it can be seen, that average stabilized moisture of compacted loam height wise the pipe, except its upper and lower links after 74 days, is w_k = 0,143, 120 – w_k = 0,134, and 180 – w_k = 0,131, so moisture increased just on 1,0% approximately.

Whereas road embankment height with compacted loam did not significantly affect on its moisture conditions and subgrade «rest» time increasing after 2 months did not significantly affect on the stabilized soil moisture value, it is advisable to perform two-factor statistical analysis of compacted clay soil stabilized moisture, depending on its soil skeleton density and plasticity index.

As a result of this statistical processing by least squares method the empirical dependence is obtained [12]

$$w_k = a_0 + a_1\left(\frac{\rho_d}{\rho_{d0}}\right) + a_2 \cdot I_p \ , \qquad (2)$$

empirical coefficient is: a_0 = 0,531; a_1 = -0,279; a_2 = 0,570.

At this multiple correlation coefficient is $r = 0{,}995$, and Fisher's ratio test $F = 106{,}326$, that is more than its table-valued $F = 4{,}89$ at test significance $p = 5\%$ and the degree of freedom $v_1 = 7$ and $v_2 = 5$.

Statistical values indicates about close relationship between the research data and therefore, about the logarithmic function (2) correctness.

The results of physical laboratory experiment related to quantitative patterns of water migration in compacted heavy and light silt loams (clay soils type – its plastic index I_p, soil skeleton density ρ_d, g/cm^3, stabilized (final) moisture of compacted clay soil w_k) are presented in Tab. 1.

The Tab. 1, in particular, clearly shows that an increase of its plasticity number I_p at the same soil skeleton density values ρ_d, stabilized moisture of compacted clay soil w_k increases.

Table 1 – Stabilized (final) moisture values of compacted heavy and light silty loams within pipe height for each preset subgrade soil skeleton density

Preset soil skeleton density, ρ_d, g/cm^3	Soil plasticity number, I_p	
	0,162	0,080
1,50	0,203 / -0,95%	0,162 / 2,36%
1,55	0,190 / -0,51%	0,143 / -0,86%
1,60	0,176 / -0,58%	0,130 / -0,21%
1,65	0,167 / 2,35%	0,144 / -2,04%

Note: numerator – the experimental values of stabilized clay soil moisture w_k; the denominator – the relative error of this parameter, calculated by the expression (2)

Also, two physical laboratory experiment series for possible water migration research in clay soils depth, compacted at stabilized moisture, were done.

In this regard the light loam was compacted at initial soil moisture, that corresponds to stabilized moisture value for this soil type (notably at plasticity number $I_p = 0{,}08$ the moisture was $w = w_k = 0{,}130$) to soil skeleton density $\rho_d = 1{,}60$ g/cm^3 at pipe height of 150 cm.

The first test series methodology does not differ from earlier described [10 – 13] (the experiment lasted for 70 days), and in the second experiment series for checking the possible capillary ascension slot channel drain with stone screening dust was filled with water (Fig. 1).

Figure 1 – Chute, filled with water for possible capillary ascension research for road embankment

The lower pipe links were input in the chute, i. e., research soil had the opportunity to boggy action. Lower pipe link was located at distance of not more than 2 – 3 cm of chute water level and as far as water evaporation it was poured into the chute periodically.

The experiment lasted for 68 days.

Moisture plot changes of compacted light silt loam height wise the pipe at soil skeleton density 1,60 g/cm^3, moisture w = 0,130 after 70 days of «rest» is shown in Fig. 2 (a).

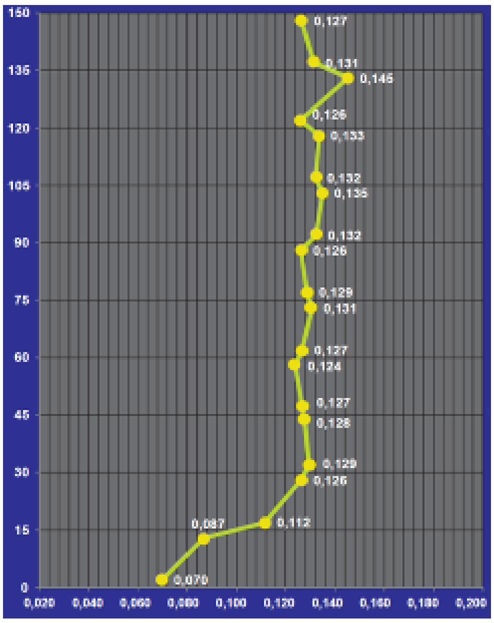

Figure 2 – Soil moisture plot changes depending on pipe height – moisture plot changes of compacted light silt loam, compacted at moisture corresponding to stabilized moisture value $w = w_k$ = 0,130, to soil skeleton density ρ_d = 1,60 g/cm^3 and pipe height of 150 cm,

Maximum moisture value w_k in accordance to the plot was 0,145, minimum moisture value in the lower pipe link was 0,070, the average moisture of pipe height wise was 0,124.

Moisture plot changes of compacted light silt loam height wise the pipe at soil skeleton density 1,60 g/cm^3, moisture w = 0,130 after 68 days of «rest» (at that research soil had the opportunity to boggy action) is presented in Fig. 2 (b).

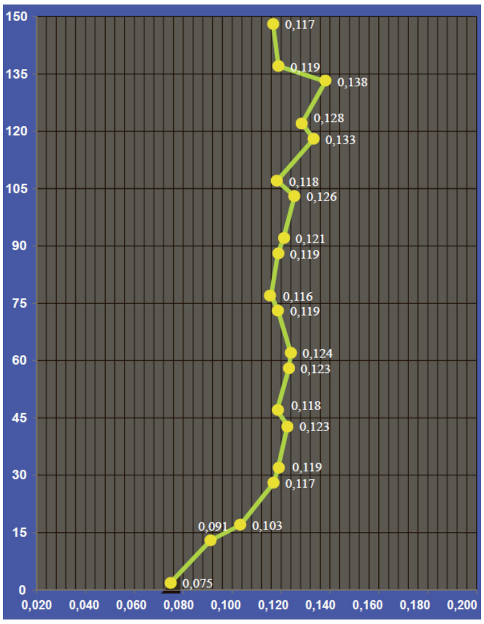

Figure 2 – Soil moisture plot changes depending on pipe height – the same, but in the experiment slot channel drain with stone screening dust was filled with water

Maximum moisture value w_k in accordance to the plot in pipe was 0,138, minimum moisture value in the lower pipe link was 0,075, the average moisture height wise the pipe was 0,121.

Fig. 2 a, b clearly shows that the average soil moisture in a plastic pipe did not change significantly (especially in the experiment, when the chute with stone screening dust was not filled with water) comparatively with initial soil moisture $w = w_k$ = 0,130 where the soil was compacted.

Thus, it can be **concluded** that subgrade clay soil moisture value, compacted at stabilized moisture (or maximum quantity of unfree water) does not significantly change through time.

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