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MOISTURE CONDITIONS PATTERNS IN ROAD EMBANKMENT CLAY SOILS DEPTH

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The work 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. Empirical dependence parameter corresponds to maximum molecular moisture capacity at what it is advisable to do the subgrade clay soils multilayer consolidation for their long-term strength ensuring.

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), statistical processing.

1. Introduction

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 [1 – 3, 6, 7, 9, 11, 13, 15 – 19]. 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 [12, 20 – 22].

When soil compacts due to high moisture, with a degree of saturation close to S_r = 1,0, then, of course, that the soil dries and held its sedimentation and therefore additional deformations, when soil compacts due to low moisture, it will be difficult to do the compaction, by the way, it's a little probability of desired soil skeleton density achieving, even with the modern mechanisms possibilities. Also national standards recommend for optimum clay soils moisture content, at the compaction by roller, to take plastic limit W_p, but this parameter is not related on how much unfree water the soil is actually containing [4, 5, 8, 12, 14, 20 – 22]. That's why for subgrade erection it's important 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 soil's deformation isn't appear. On the embankment soils condition over time significantly affects moisture, at what the compaction was done. It thus seems reasonable to improve soils compaction criteria and tried out in full-scale conditions.

2. Current state of issue and research task

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 and and so forth. So, the most common today concept in road soil compaction construction solves mainly the technological side of problem – the maximum soil skeleton density at fewest mechanism passage by one trough [12, 20 – 22].

For the reliable subgrade operation it's 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 significantly affects moisture, at what the compaction was done and the particular water type split in compacted soil [4, 5, 8, 14]. But it is still not researched quantitative impact on moisture conditions patterns in road embankment clay soils depth the next factors: soil skeleton density; compacted embankment height; the number of days, what compacted clay embankment «rests» after its erection, and before the operation [20 – 22].

In soil mechanics, minimum stress at what the soil sample is destroyed due to aeonic span of time, accepted as long-term strength limit. Stress, at what the soil sample is destroyed due to certain period of time after load imposing as a result of unchangeable soil flow and advance flow of ground, correspond to the soil long-term strength. So the theory is consider revising that the most favorable conditions for the subgrade clay soils long-term strength ensuring and in accordance minimum ground distortion during specified time operation is to compact the soil in layers at moisture, close to maximum molecular moisture capacity [12, 20 – 22].

3. Methodology and laboratory research results of road embankment clay soils moisture conditions

For new optimal compaction criteria of road embankment soils substantiation at what subgrade clay soil long-term strength is ensuring the new physical experiment methodology for water migration patterns establishment in subgrade embankment depth is developed, in the capacity factors of what it is accepted:

– clay soil type (its number plasticity I_p);
– moisture w, at what the soil was compacted;
– soil skeleton density ρ_d in the embankment;
– embankment height;
– «rest» time after subgrade erection and before it's operation.

For its realization the equipment of Geotechnics department was used, where in 2013 – 2015 years the water migration patterns heightwise through the time in soil, placed in plastic tubes (it is simulated the soil multilayer consolidation of subgrade embankment). Research soil condition and type – changeable parameter. At the unifactor experiment it is used two typical for compacted subgrade erection clay soils – heavy silt loam and light silt loam. Both research soils were taken from dug pits and cutting with depths of 3 – 4 m within the Poltava loessial plateau. In the laboratory it was stored in plastic bags.

Standard testing identify, that research soil №1 – heavy silt loam with next indicative data:

– placement water content w_0 = 0,131;
– liquid limit W_L = 0,354;
– plastic limit W_p = 0,192;
– index of plasticity I_p = 0,162.

Research soil №2 – loess loam, light silt, solid with next indicative data:

– placement water content w_0 = 0,132;
– liquid limit W_L = 0,279;
– plastic limit W_p = 0,191;

– index of plasticity I_p = 0,08.

Soil skeleton density was accepted as a changeable factor, and initial degree of saturation of compacted clay soils in all experiments was adjusted to $S_r = 0{,}85$. Accordingly soil moisture at each test 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.

For the work realization it is used: weigher; hand sprinkler; 40 plastic pipes links with dimensions of 50 mm (external diameter) × 150 mm (the height of each pipe link); vertical frame; drainage channel; hand tamper; spatula (Fig. 3.1, a – c).

Fig. 3.1 – Stages of compacted road embankment 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 – erected to a common pipe links height

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 pipes 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_0 = 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. 3.1, a).

The soil was moistened to a given moisture w by hand sprinkler (Fig. 3.1, b) and mixed by spatula for the uniform moistening of research soil portion (Fig. 3.1, c). Then by portions it was moved in pipes and uniform compacted using hand tamper with certain marks by its height (Fig. 3.1, d, Fig. 3.2, a) all time to thickness of 30 mm, and then pipe link (150 mm) was connected to a total height (Fig. 3.1, e).

a b c d

Fig. 3.2 – Stages of compacted subgrade loam moisture conditions laboratory studies: a – hand tamper for soil compaction; b – vertical frame for pipe placement with compacted; c, d – pipes, filled with compacted soil with marks upper about initial soil skeleton density ρ_d and its required moisture w

These pipes with compacted in layers soil were installed on a metal vertical frame (Fig. 3.2, b, c, d). The lower pipe ends was installed in drainage channel, filled with stone screening dust (stone chips). Thus, free (gravity) water had opportunity for the migration at all soil pipe height, what imitate it's migration within road embankment depth. The top of all pipes with compacted soil layers was hermetically closed to avoid evaporation of water «up».

On each pipe the dates of initial soil skeleton density ρ_d and defined moisture w was sticked down. Then pipes was left on vertical frame alone, for the «rest».

After allowed time «rest» all pipes were dismantled into separate links. From each link it was selected at least two soil sample in bottles, and by normative weight method the final (stabilized) moisture w_k of compacted soil was determined. So, within the laboratory experiment it was done:

– 4 experiment series for relation of final soil moisture №1 from soil skeleton density ρ_d = 1,50 – 1,65 g/cm^3 at pipe height 150 cm substantiation;

– 4 analogous test series with research soil №2 at ρ_d = 1,50 – 1,65 g/cm^3 and pipe height 150 cm;

– 5 experiment series for relation of final soil moisture №2 depending on pipe height 45, 90, 150, 210 and 285 cm and ρ_d = 1,55 g/cm^3;

– 3 test series for relation of final soil moisture №2 depending on waiting time

74, 120 and 180 days at ρ_d = 1,55 g/cm^3 revealing;

– 2 experiment series for relation of final soil moisture №2 from soil skeleton density ρ_d = 1,60 g/cm^3 and pipe height 150 cm at placement water content changing and probable capillary ascension of water.

The exact maximum molecular moisture capacity values was determined in laboratory conditions by moisture-holding capacity surroundings method. The experiment was conducted according to the following algorithm. It was taken 50 – 70 g of air-dried soil, what was triturate in a mortar, sieved through a sieve with holes of 0,5 mm.

Soil that passed through a sieve of 0,5 mm was mixed up in a cup to high-plastic condition. On a piece of batiste (tamise cloth) it was laid the template – 2 mm thick plate with a hole diameter of 50 mm. Template was filled with soil paste, the excess was cut by knife. Soil template was taked off.

The prepared soil template at top was covered by textile, and on both sides was put filter paper bags (for 20 sheets). Rigid plate was placed above and below, the template was installed under a hydraulic press and was pressured to 6,5 MPa, which was sustained for 10 minutes.

After pressing soil template was picked down and moisture was determined, just as in previous method of soil «rest» in pipes.

To implement this experiment it was used the same soil as at the previous tests. In particular, 5 heavy and light silt loams cores was selected.

The results of maximum molecular moisture capacity (maximum quantity of unfree water) of heavy and light silt loams determining is presented in the Tab. 3.1 and 3.2.

Table 3.1 – Maximum molecular moisture capacity values of research soil №1

Clay soil plasticity number, I_p	Maximum molecular soil moisture capacity, w_k	Average value of maximum molecular soil moisture capacity, w_k	Variation coefficient of value w_k, υ
0,162	0,169	0,160	0,040
	0,164		
	0,161		
	0,157		
	0,150		

Table 3.2 – Maximum molecular moisture capacity values of research soil №2

Clay soil plasticity number, I_p	Maximum molecular soil moisture capacity, w_k	Average value of maximum molecular soil moisture capacity, w_k	Variation coefficient of value w_k, υ
0,080	0,144	0,135	0,045
	0,140		
	0,134		
	0,131		
	0,127		

Consequently, new methodology of water migration in road embankment clay soils depth running of laboratory experiment through time changes research of clay loam moisture, placed in plastic pipes and compacted at water saturation factor S_r = 0,85 to soil skeleton density 1,50 – 1,65 g/cm^3 was developed and realized by practice. Changeable factors were: clay soil type – heavy silt loam and light silt loam; pipe height – from 0,45 m to 2,85 m; «rest» time after subgrade erection and before it's operation, – from 60 – 180 days. The value of final moisture (maximum molecular moisture capacity) by the new method did not significantly differ from the values, obtained by well tested moisture-holding capacity surroundings method, in particular the averages values difference of maximum molecular moisture capacity by the method of soil «rest» in pipes, compared with the existing method, doesn't exceed 5%.

The dependings graphs of compacted loam moisture are drew:

– heavy silt at soil skeleton density 1,50 g/cm^3 moisture w = 0,250, at soil skeleton density 1,55 g/cm^3 moisture w = 0,231, at soil skeleton density 1,60 g/cm^3 moisture w = 0,214, at soil skeleton density 1,65 g/cm^3 moisture w = 0,198 after 62 days of «rest» and pipe height of 1,50 m;

– light silt at soil skeleton density 1,50 g/cm^3 moisture w = 0,250, at soil skeleton density 1,55 g/cm^3 moisture w = 0,231, at soil skeleton density

1,60 g/cm^3 moisture w = 0,214, at soil skeleton density 1,65 g/cm^3 moisture w = 0,198 after 62, 74, 77 i 75 days of «rest» accordingly and pipe height of 1,50 m;
– light silt heightwise the pipe of 0,45 m, 0,9 m, 1,50 m, 2,10 m and 2,85 m at soil skeleton density 1,55 g/cm^3 moisture w = 0,231 after 59, 59, 74, 62 and 66 days of «rest» accordingly;
– light silt at soil skeleton density 1,55 g/cm^3 moisture w = 0,231 after 74, 120 and 180 days of «rest» and pipe height of 1,50 m.

Examples result of moisture plots changes of compacted heavy and light silt loams at soil skeleton density 1,50 g/cm^3 moisture w = 0,250 and pipe height of 1,50 m are shown in Fig. 3.3, a and 3.3, b accordingly.

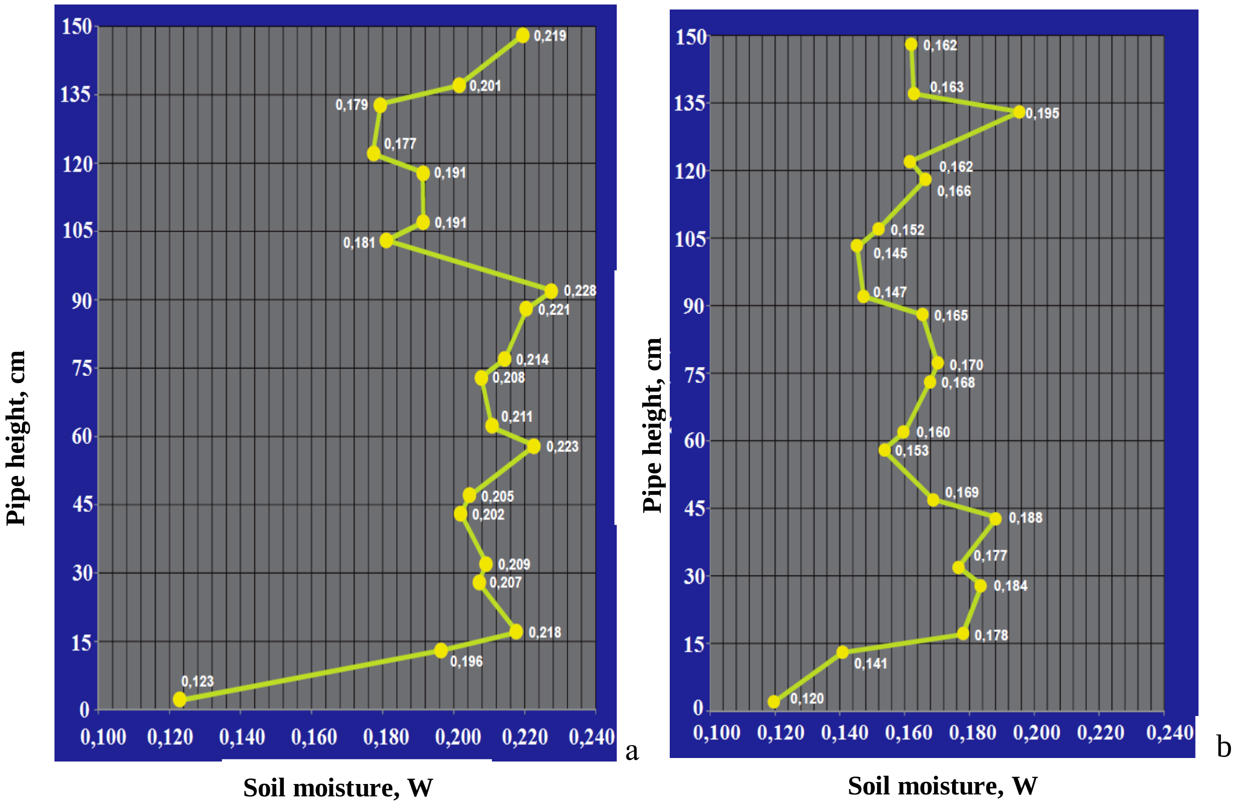

Fig. 3.3 – Heavy silt loam moisture (a) and light silt loam moisture (b) from soil skeleton density ρ_d = 1,50 g/cm^3 and pipe height of 150 cm dependings

In most experiments it is noted the potential to moisture loam increasing at the upper pipe link and its decreasing at lower link. Therefore, the calculation of average moisture values and the variation coefficient of this parameter heightwise the pipe the moisture values in upper and lower links are not taken into account.

Example of moisture plot changes of compacted light silt loam heightwise the pipe of 0,45 m at soil skeleton density 1,55 g/cm^3, moisture w = 0,231 after 59 days of «rest» is shown in Fig. 3.4.

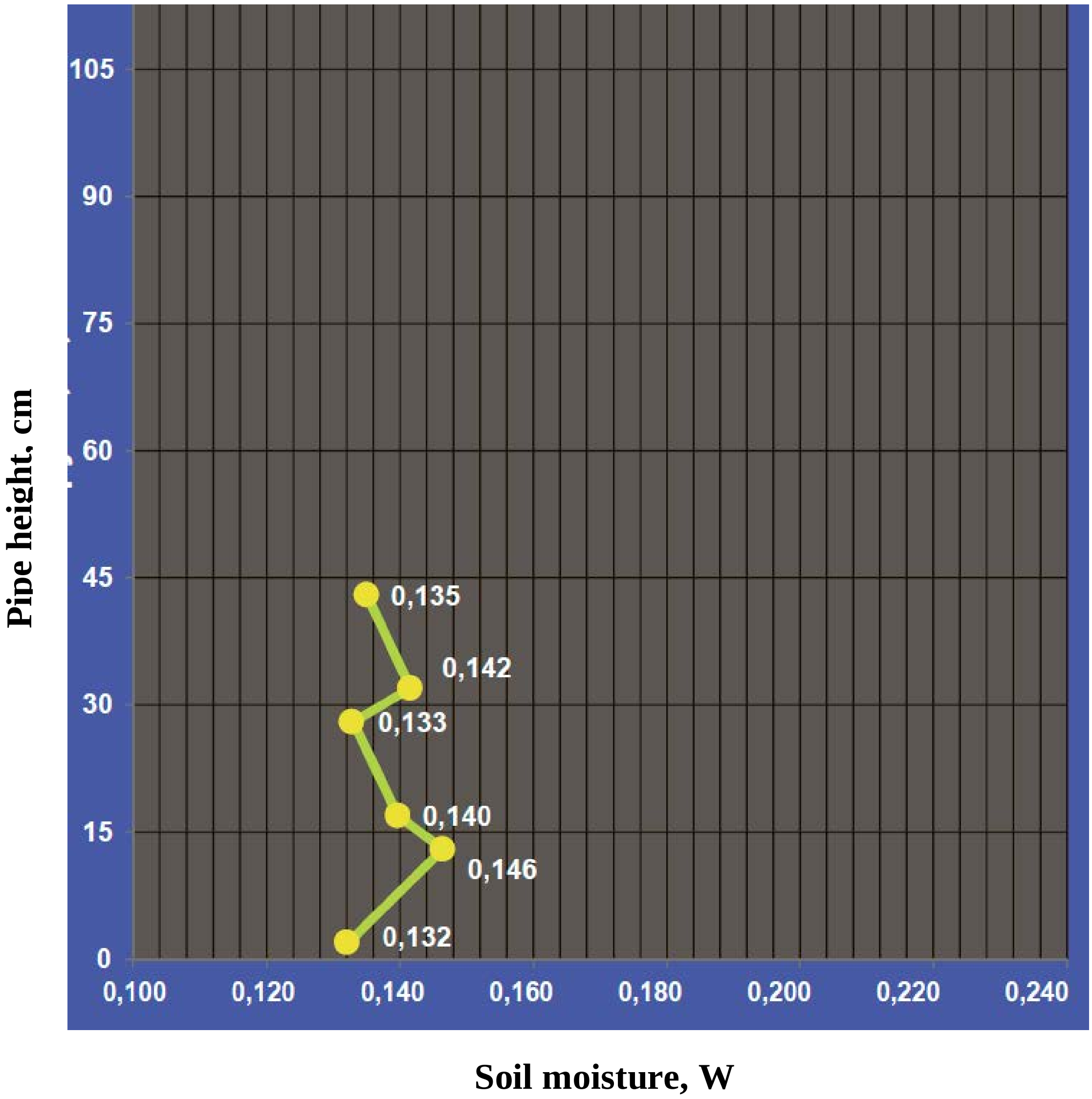

Fig. 3.4 – Moisture plot changes of compacted light silt loam heightwise the pipe of 0,45 m at soil skeleton density 1,55 g/cm^3

Analogous moisture plot changes of compacted light silt loam heightwise the pipe of 2,85 m at soil skeleton density 1,55 g/cm^3, moisture w = 0,231 after 66 days of «rest» is shown in Fig. 3.5.

Moisture plot changes of compacted light silt loam heightwise the pipe at soil skeleton density 1,55 g/cm^3, moisture w = 0,231 after 74 days of «rest» is shown in Fig. 3.6.

Pipe height – 150 cm. Maximum moisture value in accordance to the plot was 0,164, minimum moisture value in the lower pipe link was 0,128, the average moisture heightwise the pipe was 0,143.

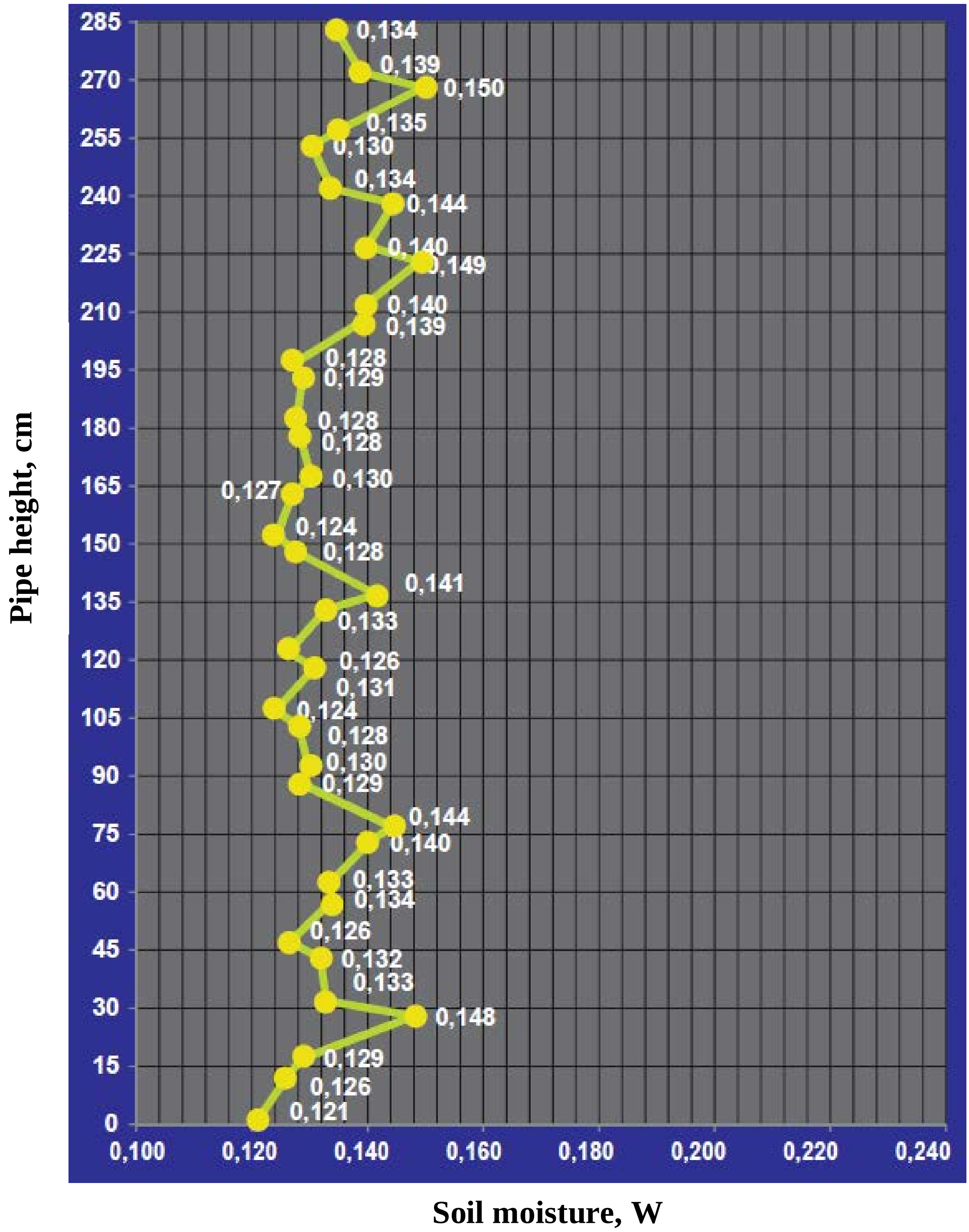

Fig. 3.5 – Moisture plot changes of compacted light silt loam heightwise the pipe of 2,85 m at soil skeleton density 1,55 g/cm^3

Moisture plot changes of compacted light silt loam heightwise the pipe at soil skeleton density 1,55 g/cm^3, moisture w = 0,231 after 120 days of «rest» is shown in Fig. 3.7. Maximum moisture value in accordance to the plot was 0,148, minimum moisture value in the lower pipe link was 0,121, the average moisture heightwise the pipe was 0,134.

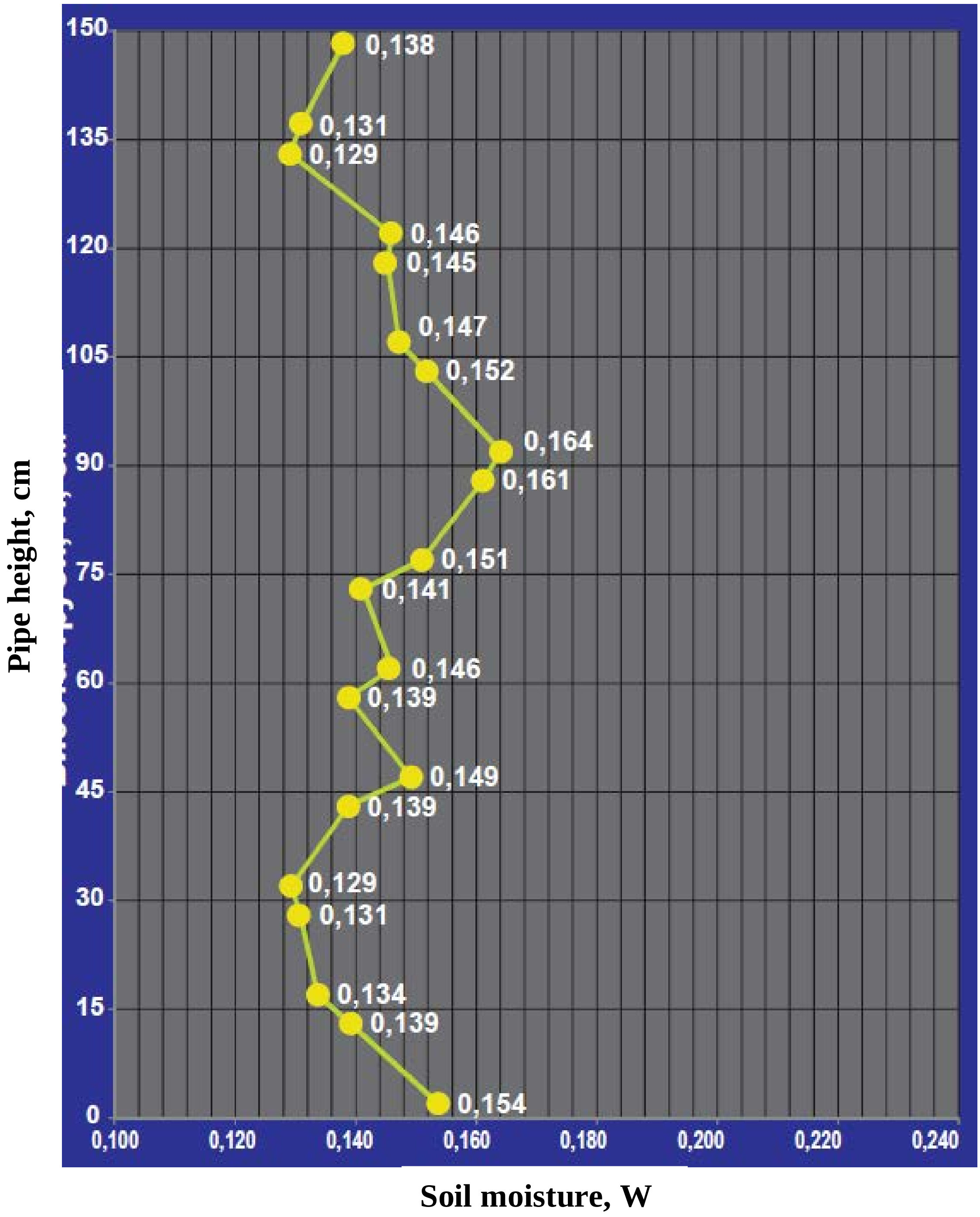

Fig. 3.6 – Moisture plot changes of compacted light silt loam at soil skeleton density 1,55 g/cm^3 and pipe height of 150 cm («rest» time 74 days)

Moisture plot changes of compacted light silt loam heightwise the pipe at soil skeleton density 1,55 g/cm^3, moisture w = 0,231 after 180 days of «rest» is shown in Fig. 3.8. Maximum moisture value in accordance to the plot was 0,141, minimum moisture value in the lower pipe link was 0,117, the average moisture heightwise the pipe was 0,131.

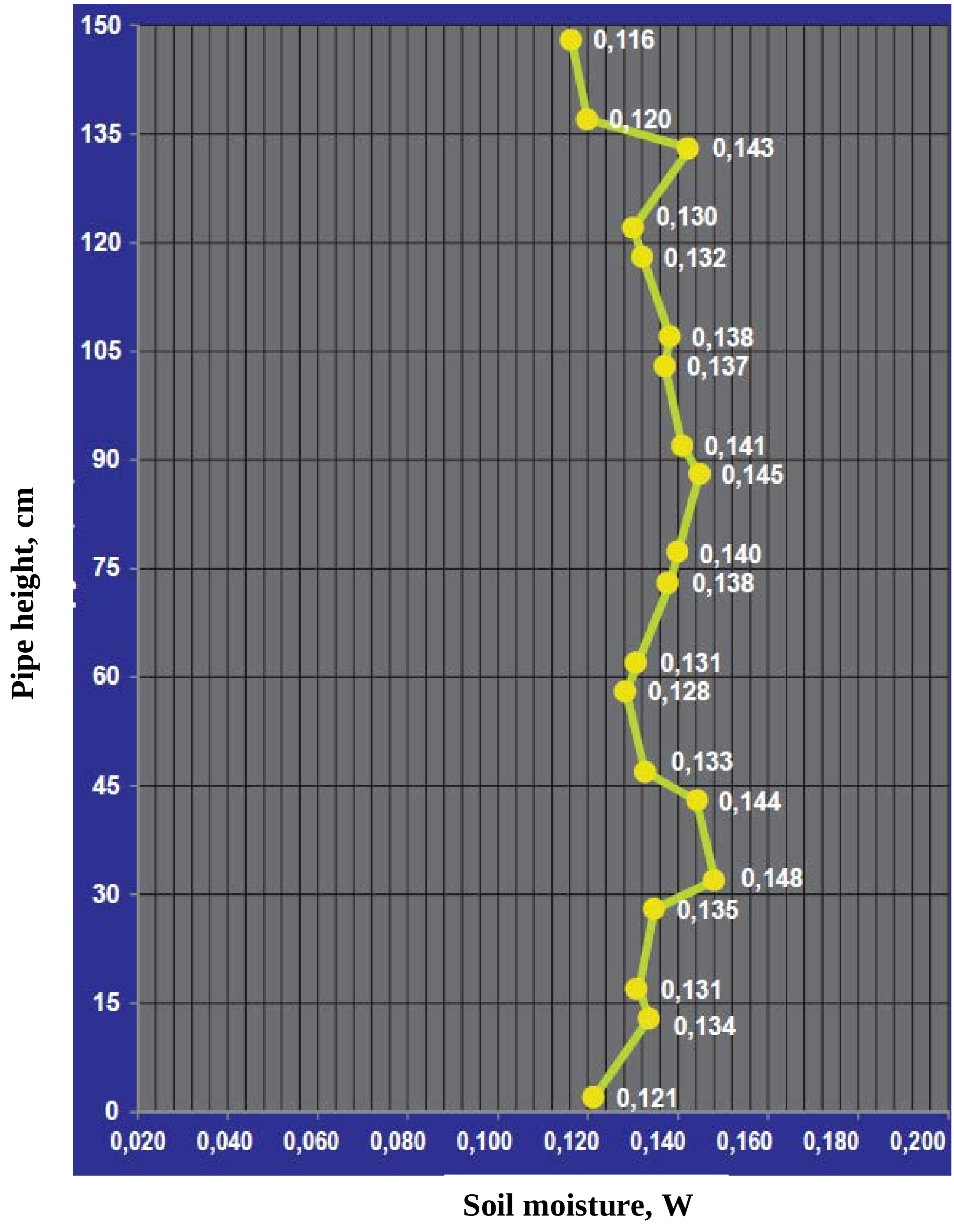

Fig. 3.7 – Moisture plot changes of compacted light silt loam at soil skeleton density 1,55 g/cm^3 and pipe height of 150 cm («rest» time 120 days)

Consequently, from plotted by the experiments data graphs it is noted:

– with clay soil skeleton density increasing, it’s moisture decreases;

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

– waiting time 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 pipe height (with «rest» time increasing from 74 to 120 and 180 days the loam moisture increased on 1 %).

– soil plasticity number I_p make a big difference on moisture condition, precisely, the more this value (i.e, the more content ratio of clay particles in soil), the higher its final moisture.

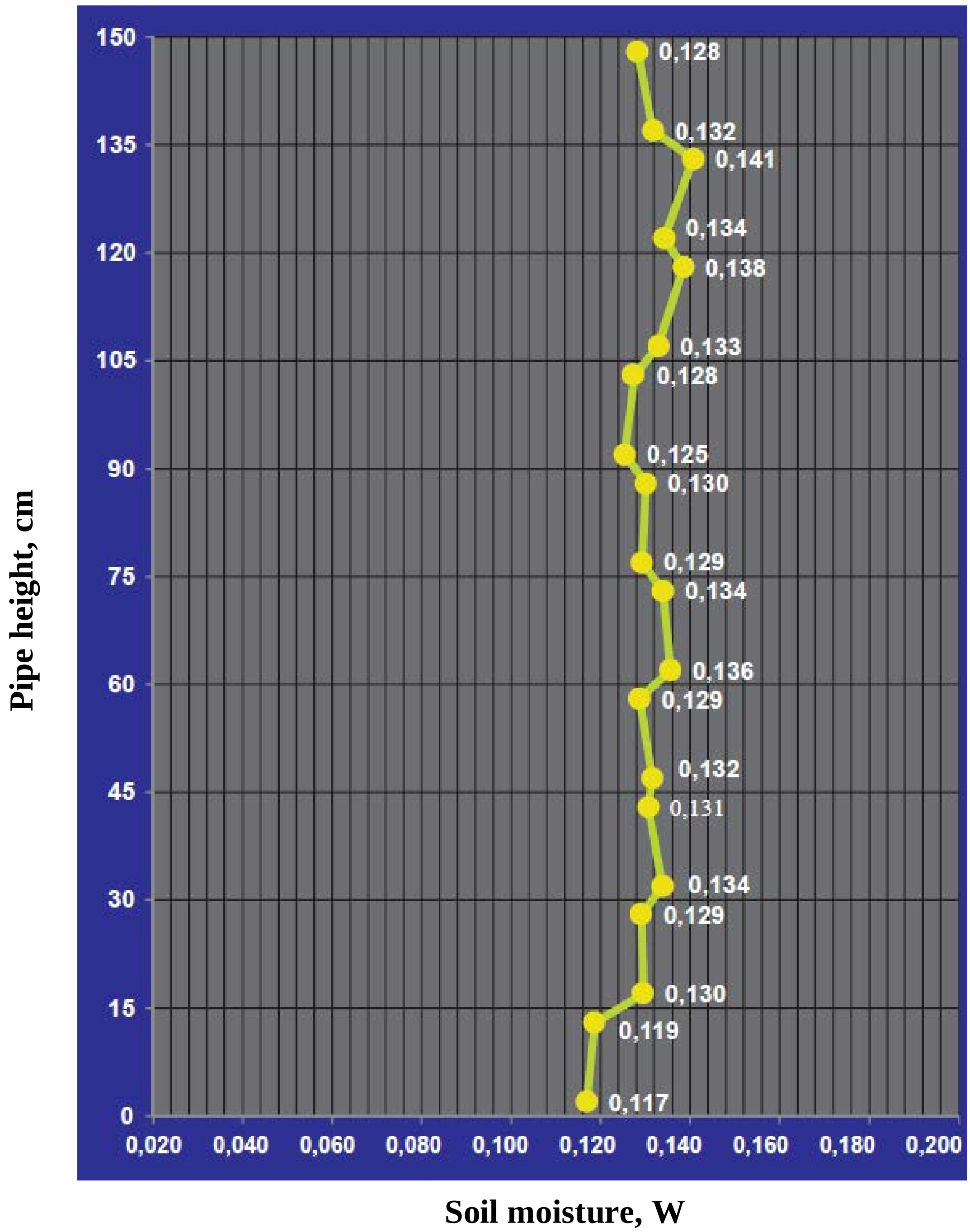

Fig. 3.8 – Moisture plot changes of compacted light silt loam at soil skeleton density 1,55 g/cm^3 and pipe height of 150 cm («rest» time 180 days)

Thus, for the following analysis new experimental data of compacted subgrade clay loam moisture conditions depending on their type, soil skeleton density, embankment height and time «rest» before it's operation are obtained.

4. Qualitative moisture conditions patterns in road embankment clay soils depth by the results of experiment

The value of stabilized moisture generally corresponds to maximum molecular moisture capacity, at what it is advisable to do the subgrade clay soils multilayer consolidation for their long-term strength ensuring. So from the perspective of clay soil long-term strength ensuring w_k just that parameter it is viable to accept as optimum moisture content W_{opt} of soil compaction.

The average results of compacted clay soil stabilized moisture w_k determining by whole pipe height, except it's upper and lower links for each preset soil skeleton value 1,50 – 1,65 g/cm^3 placed in Tab. 4.1 and 4.2.

Table 4.1 – Average of final moisture w_k of compacted heavy loam (research soil № 1) heightwise whole pipe

Preset soil skeleton density ρ_d, g/cm^3	Corresponding void volume ratio, e	Preset soil moisture w (at S_r = 0,85)	Final soil moisture, w_k	Variation coefficient w_k, υ
1,50	0,786	0,250	0,203	0,071
1,55	0,729	0,231	0,190	0,068
1,60	0,675	0,214	0,176	0,063
1,65	0,624	0,198	0,167	0,065

Table 4.2 – Average of final moisture w_k of compacted light loam (research soil № 2) heightwise whole pipe

Preset soil skeleton density ρ_d, g/cm^3	Corresponding void volume ratio, e	Preset soil moisture w (at S_r = 0,85)	Final soil moisture, w_k	Variation coefficient w_k, υ
1,50	0,786	0,250	0,162	0,072
1,55	0,729	0,231	0,143	0,070
1,60	0,675	0,214	0,130	0,072
1,65	0,624	0,198	0,114	0,068

In the last column of both tables the variation coefficient values of w_k parameter is presented, by what the soil can be accepted as homogeneous.

By data of Tab. 4.1 and 4.2 the dependings graphs (Fig. 4.1 a, b) are drew:

– graph 1 – of soil moisture w, at what both research soils were compacted from soil skeleton density ρ_d in road embankment (pipe);

– graph 2 – stabilized soil moisture w_k of already compacted loams after subgrade «rest» time from ρ_d within pipe height.

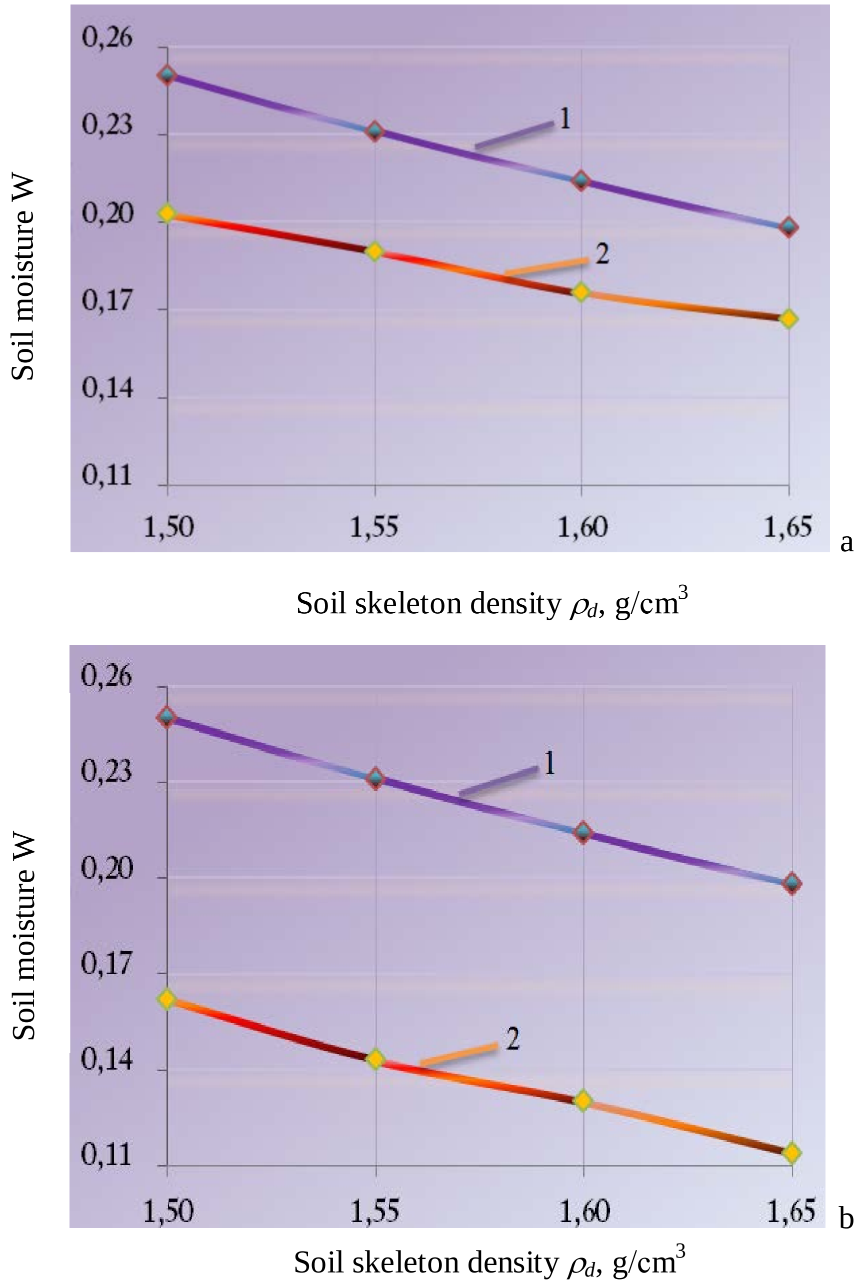

Fig. 4.1 – Plots relation of soil moisture *w* at what the loam was compacted, (1) and stabilized (final) soil moisture w_k of already compacted heavy loam from ρ_d after the «rest» time of subgrade (2) from soil skeleton density within pipe height: a – heavy loam; b – light loam

As a result of statistical processing by least squares method of research data Tab. 4.1 (and Fig. 4.1) 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 [21]

$$w_k = a + b\ln\left(\frac{\rho_d}{\rho_{d0}}\right) \quad , \qquad (4.1)$$

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 in accordance is: r = 0,997; v = 0,008, what indicates about close relationship between the experimental data and about the correctness of their approximation by the logarithmic function [21].

Analogous logarithmic dependence is obtained also for stabilized moisture value w_k of compacted light silty loam (research soil № 2). Empirical coefficient of equation (4.1) is: a = 0,362; b = - 0,494.

At this multiple correlation coefficient r and variation coefficient v values in accordance is: r = 0,998; v = 0,0115, what indicates about close relationship between the experimental data and about the correctness of their approximation by the logarithmic function [21].

Comparing by data of Tab. 4.1 and Tab. 4.2 and Fig. 4.1 a, b the final average soil moisture values w_k of compacted loams after two months «rest» with initial moisture values w of this soil we can state, that:

– final average soil moisture value w_k of compacted loams compared with initial moisture w, at what the clay soil was compacted, decreased for all soil skeleton density value ρ_d almost for all tube height except it's upper link, for what soil moisture approached to the value w_{sat},what 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 (refer, in particular, on graph 2 in Fig. 4.1 a, b), what explains by the fact that with ρ_d increasing due to the fact of ρ_d increasing film thickness of unfree water something decreases and besides, the coefficient of permeability also decreases, what reduces to moisture speed redistribution;

– stabilized soil moisture w_k in all cases come to be less than soil plasticity number W_p and approach to its, so-called, maximum molecular moisture capacity w_{mm});

– moisture decreasing of initial w, at what the soil was compacted, within highway embankment in practice causes to it's additional settlement.

The average values of compacted light silt loam stabilized moisture w_k determining depending 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 heightwise the pipe of 0,45 m, 0,9 m, 1,50 m, 2,10 m and 2,85 m shows, that the height of compacted clay soil as a part of subgrade did not significantly affect its moisture condition.

From the moisture plots changes analysis of light loam heightwise the embankment (pipe) 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, one can see, that average stabilized moisture of compacted loam heightwise the pipe, except it's 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, for this reason, 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 [21]

$$w_k = a_0 + a_1\left(\frac{\rho_d}{\rho_{d0}}\right) + a_2 \cdot I_p \tag{4.2}$$

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, what more than its table-valued $F_{табл}$ = 4,89 at test significance p = 5% and the degree of freedom ν_1 = 7 and ν_2 = 5.

Statistical values indicates about close relationship between the research data and therefore, about the logarithmic function (4.2) 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. 4.3.

The Tab. 4.3, 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 4.3 – 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	$\frac{0,203}{-0,95\%}$	$\frac{0,162}{2,36\%}$
1,55	$\frac{0,190}{-0,51\%}$	$\frac{0,143}{-0,86\%}$
1,60	$\frac{0,176}{-0,58\%}$	$\frac{0,130}{-0,21\%}$
1,65	$\frac{0,167}{2,35\%}$	$\frac{0,114}{-2,04\%}$

Note: numerator – the experimental values of stabilized clay soil moisture w_k; the denominator – the relative error of this parameter, calculated by the expression (4.2)

It is also was done two physical laboratory experiment series for possible water migration research in clay soils depth, compacted at stabilized moisture.

In this regard the light loam was compacted at initial soil moisture, what 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 ρ_d = 1,60 g/cm^3 at pipe height of 150 cm.

The first test series methodology is not differs from afore-described (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. 4.2).

Fig. 4.2 – 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 a 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 heightwise the pipe at soil skeleton density 1,60 g/cm^3, moisture w = 0,130 after 70 days of «rest» is shown in Fig. 4.3.

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 heightwise the pipe was 0,124.

Moisture plot changes of compacted light silt loam heightwise 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. 4.4.

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 heightwise the pipe was 0,121.

Fig. 4.3 and Fig. 4.4 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) compared with initial soil moisture $w = w_k$ = 0,130, at what the soil was compacted.

Consequently, subgrade clay soil moisture value, compacted at stabilized moisture (or maximum quantity of unfree water) does not significantly change through time.

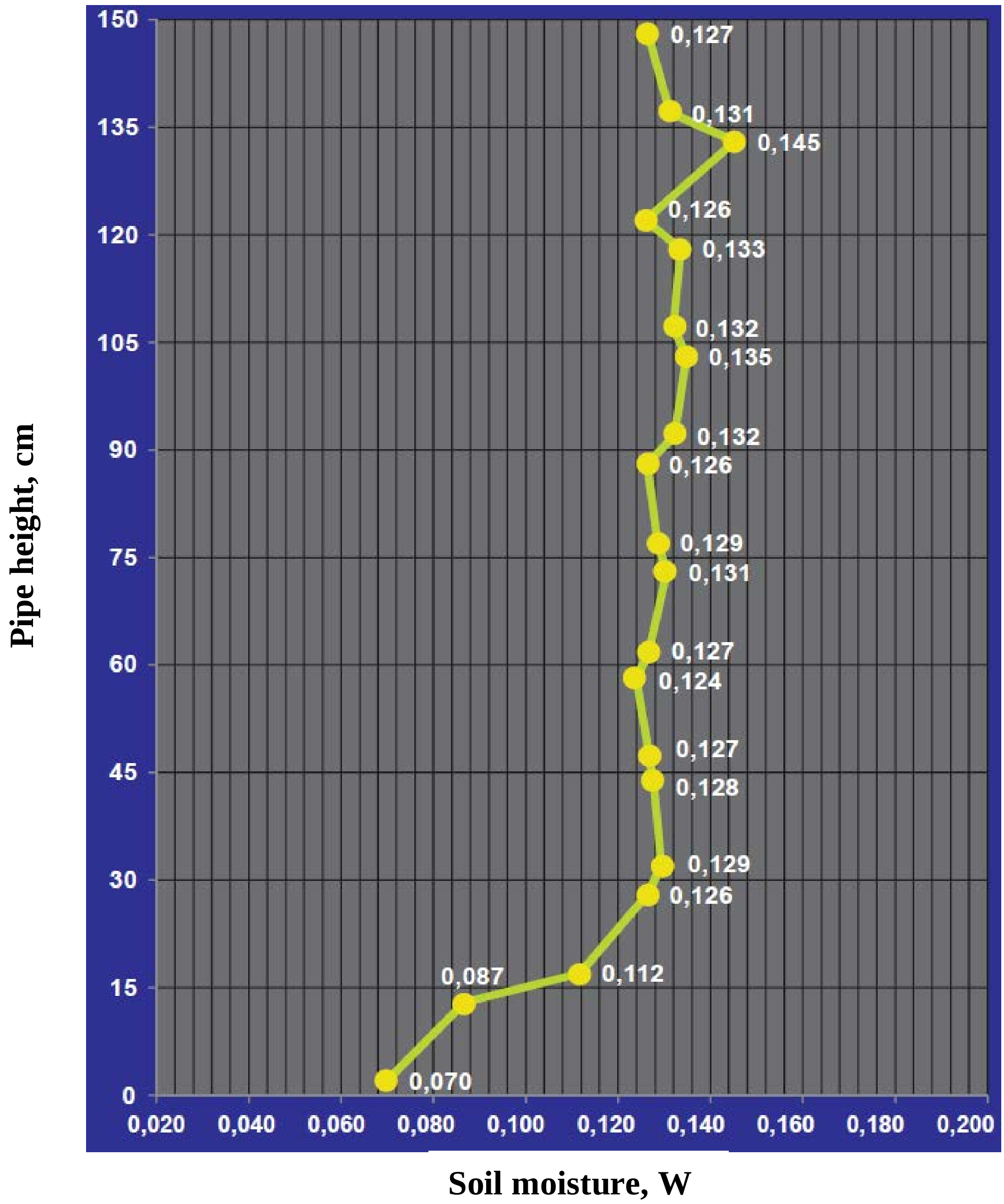

Fig. 4.3 – Moisture plot changes of compacted light silt loam, compacted at moisture corresponding to stabilized moisture value $w = w_k$ = 0,130, to soil skeleton density ρ_d = 1,60 g/cm^3 and pipe height of 150 cm

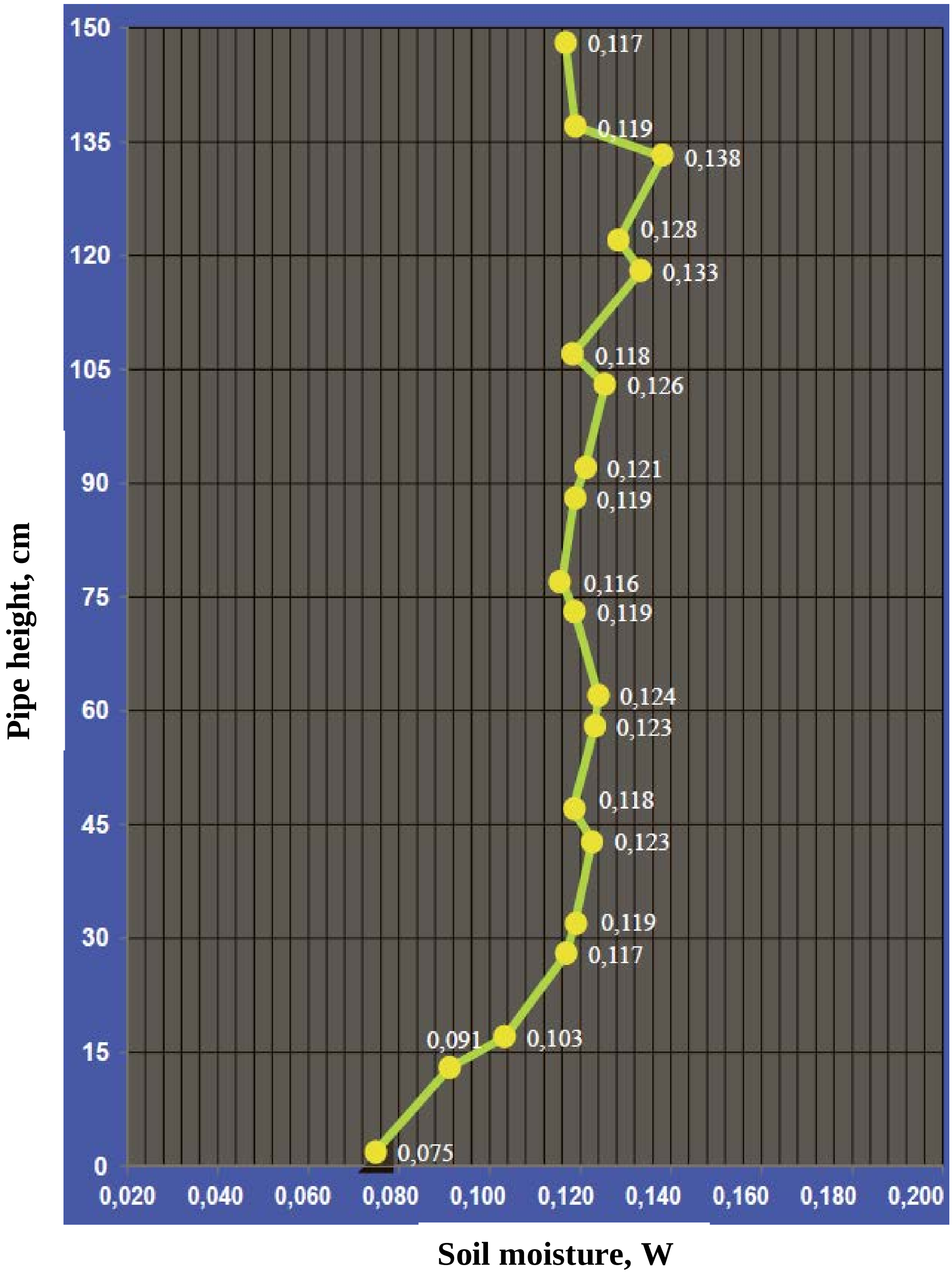

Fig. 4.4 – Moisture plot changes of compacted light silt loam, compacted at moisture corresponding to stabilized moisture value $w = w_k = 0{,}130$, to soil skeleton density ρ_d = 1,60 g/cm^3 and pipe height of 150 cm (in the experiment slot channel drain with stone screening dust was filled with water)

Conclusions

1. Agreeably with standards maximum soil skeleton density ρ_{dmax} and optimum moisture content W_{opt}, are prescribed from obtained for particular soil type and dynamic effect parameters without mechanism peculiarities considering. But the standarts is fall behind the machinery facilities, because with compaction energy per unit of volume increasing the optimum moisture content and maximum soil skeleton density values considerably change. By the full-scale experiment it is approved the theory, that for subgrade erection long-term strength ensuring and minimum deformations during its normative operational time is to do the soil multilayer consolidation at moisture, close to maximum quantity of unfree water.

2. For new optimal compaction criteria substantiation, at what subgrade clay soils long-term strength ensures, new author's method of physical laboratory experiment for compacted heavy and light silt loam relationships water migration establishment, including the stabilized (or final) clay soil moisture values, depending on their type (number plasticity), soil skeleton density, embankment height and time «rest» of subgrade before it's operation is developed and realized.

3. As a result of statistical processing by least squares method the research laboratory and field data, 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. Empirical dependence parameter corresponds to maximum molecular moisture capacity at what it is advisable to do the subgrade clay soils multilayer consolidation for their long-term strength ensuring. The embankment height of multilayer consolidation and subgrade «rest» time after 2 months did not significantly affect the stabilized soil moisture.

4. Clay soil embankment multilayer consolidation it is desirable to do at moisture, that corresponds to maximum molecular moisture capacity, accepted by the expression (4.2) depending on soil skeleton density specified rate and plasticity number of this soil. The value of this moisture is lower than plastic limit, but present-day compacted machines makes it possible to sufficiently increase the specific compaction energy for the soil compaction at moisture less than plastic limit with a maximum soil skeleton density.

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