Designing and Construction of Roads, Subways, Airfields, Bridges and Transport Tunnels

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V. P. Matua[1], Ye. N. Isaev[2]

STUDIES OF THE INFLUENCE OF THE MOISTURE CONTENT AND DENSITY OF SUBGRADE SOIL ON THE ACCUMULATION OF RESIDUAL STRAIN

Don State Technical University[1, 2]
Russia, Rostov-on-Don

[1]*D. Sc. in Engineering, Prof. of the Dept. of Highways, tel.: +7-928-226-58-07, e-mail: vpmatua@mail.ru*
[2]*PhD student of the Dept. of Highways, tel.: +7-918-576-86-39, e-mail: evgenyisaev91@mail.ru*

Statement of the problem. The influence of soil humidity on residual deformations and the effect of soil density on the intensity of capillary water saturation in the laboratory is studied. The humidity and residual deformation in the soil of the roadbed is measured on sections of highways with different coefficients of compaction.
Results. The results of soil tests with varying humidity on the dynamic test device are presented. The investigation of soils with a varying density for intensive capillary water saturation was carried out. The analysis of the measurements of humidity and residual deformation in the soil of the roadbed with varying compaction coefficients was carried out.
Conclusions. As a result of the study of the influence of soil moisture on the accumulation of residual deformations under the influence of dynamic loads, it was found that the total value of residual deformations and the intensity of its accumulation in soil samples significantly depend on the humidity. The analysis of the obtained data on the intensity of capillary water saturation showed that change in the humidity of cohesive soils depends significantly on the soil compaction coefficient. Thus, there is a need to increase the coefficient of compaction on the sections of the road with a high likelihood of excessive humidity of subgrade soil throughout the calculated period.

Keywords: humidity, soil, residual strain, density, dynamic test tool.

Introduction. One of the essential problems facing this country's road industry is rutting caused by residual (plastic) deformations in construction layers of pavements and the operating layers of the subgrade in particular [3, 6—8, 13, 19].

One of the most important characteristics of subgrades is that crucial for design solutions and operation of pavements is the density of the subgrade of the operating layer (1.5 m from the top of the pavement). Therefore it is of primary importance to improve the compaction of subgrades and methods of enhancing the density [1, 5, 9, 11, 13]. The complexity of the problem in question is that there should be such operating conditions of the subgrade that would allow high construction compaction coefficients to be maintained or be reduced to a minimum during the life cycle.

One of the major factors contributing to the strength and deformation characteristics of subgrades is temperature and humidity mode. Change in the humidity level first of all impacts their load-bearing capacities that are specified at the designing stage. High humidity levels similar to those at the fluidity boundary could be most severe. This leads to a sharp decrease in its strength and deformation characteristics and much lower resistance to dynamic impact of vehicles [4, 10, 20—23]. All things considered, the staff of the Don State Technical University conducted a series of studies of the effect of humidity and density of subgrades on residual deformations under dynamic transport loads. The tests were carried out on a specially developed dynamic test tool [15, 17, 18] (Fig. 1). In this tool the maximum acceptable deformations for subgrades are 4.5 mm [14].

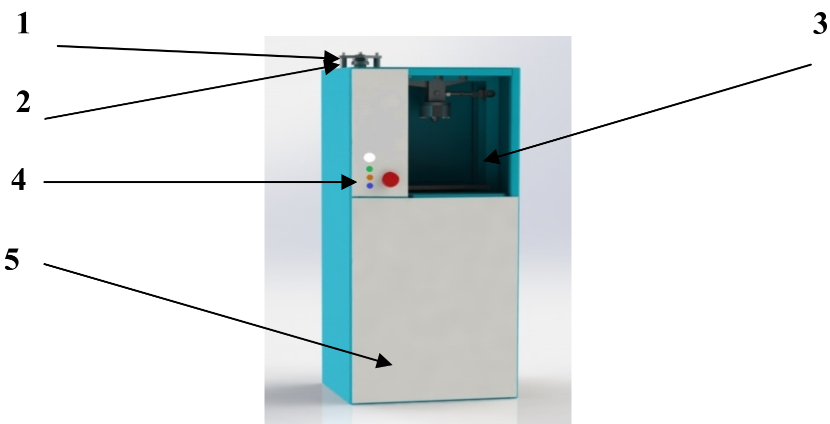

Fig. 1. General view of the dynamic test tool:
1 is a hydraulic grip; 2 are springs; 3 is a thermostat chamber; 4 are indicators; 5 are facing elements

1. Methods of subgrade testing on the dynamic test tool and the results. The study of the resistance of different types of subgrades to actual dynamic loads and climatic factors is carried out as follows: designing subgrade samples, preparing them for testing, dynamic load tests [12].

The tests were performed on samples of loamy and clayey soils. During the preliminary laboratory tests the physical and mechanical indices were determined in order to identify the dependence of rheological properties of soils and their residual deformations.

Using the example in Fig. 2 there are the graphs of the dynamic loads tests of the loamy soil samples with the plasticity number $I_p = 13$ with different humidity from 0.53 to 0.84 Wт obtained following the water saturation with the compaction coefficients 0.98.

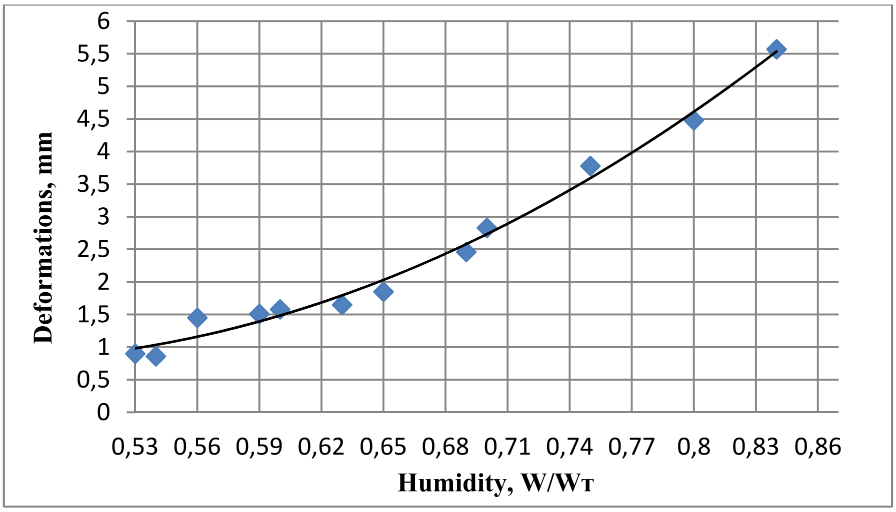

Fig. 2. Graph of residual deformations of the loamy soil depending on the soil humidity

Fig. 3 shows the graphs of the dynamic load tests of the clayey soil samples with the plasticity number $I_p = 18$ with the humidity varying from 0.53 to 0.75 Wт obtained following the water saturation with the compaction coefficient 0.98.

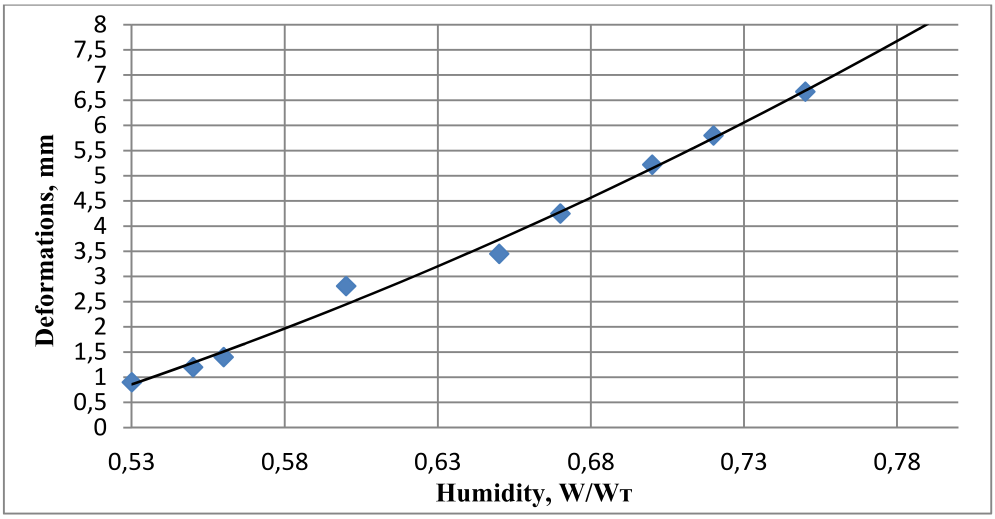

Fig. 3. Graph of residual deformations of the loamy soil depending on the soil humidity

The analysis of the results of the laboratory tests in Fig. 2 indicates that the residual deformations in the soil samples are considerably dependent on the humidity. If the residual deformations in the samples of the loamy soil with the compaction coefficient K_{comp} = 0.98 and the humidity 0.55 W_T is 1.08 mm, this same index for the same soil with the humidity 0.7 W_T is 2.83 mm. As the humidity of the soil goes up to 0,8 W_T, the residual deformations in the investigated samples reaches 4.52 mm. At the humidity of 0.8 W_T the residual deformations in the soil under discussion are over the acceptable limit.

A similar analysis of the results was performed for the loamy soils. The residual deformations in the loamy soil samples with the compaction coefficients K_{comp} = 0.98 and humidity 0.55 W_T is 1.22 mm while the same index for the same soil over the acceptable limit is 3.45 mm. As the soil humidity goes up to 0.7 W_T, the residual deformations in the samples of the investigated soil goes up to 5.22 mm. At the humidity 0.7 W_T the residual deformations in the samples of the investigated soil are over the acceptable limit.

2. Capillary water saturation tests of the soils. In order to study the influence of the soil density on the capillary water saturation, a series of laboratory experiments using a capillary water saturation tool was conducted in compliance with the GOST (ГОСТ) 23558-94 “Crushed-stone gravel sandy soils treated with non-organic binders for road and airfield construction”. The tests were carried out on the samples of loamy and clayey soils with the plasticity number 13 and 18 respectively with the compaction coefficient ranging from 0.98 to 1.04.

The loamy soil samples with the optimal humidity W_{opt} = 17.1 % with the compaction coefficients 0.98, 1.01 and 1.04 were exposed to capillary water saturation at the same time and under the same conditions. Water saturation of the samples was conducted through a wet sand layer using the capillary water saturation.

The vessel was filled with water till it reached a certain level (the water level was maintained throughout the experiment). There was also a frame with a lattice bottom with filter paper put on it prior to the experiment. A layer of fine homogeneous sand was poured over the filter paper and after a day following the saturation the soil samples were introduced. After certain periods of time they were weighed. As an example, Fig. 4—5 shows the results of the experimental studies.

Similar studies were performed for the clayey soil with the optimal humidity Wopt = 18,03 % and the compaction coefficients: 0.98; 1.01 and 1.04. As an example, Fig. 6—7 shows the results of the experimental studies of the clayey soil.

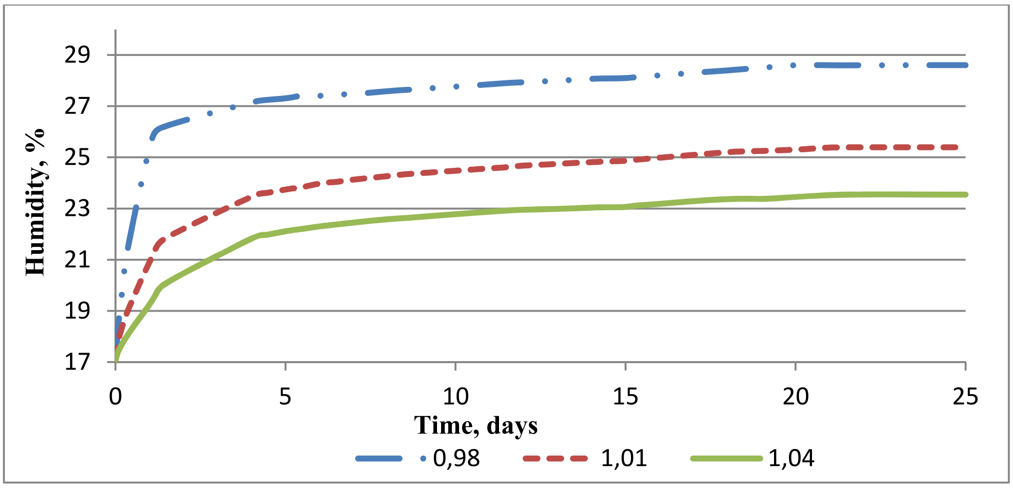

Fig. 4. Changes in the humidity of the loamy soil samples of varying density

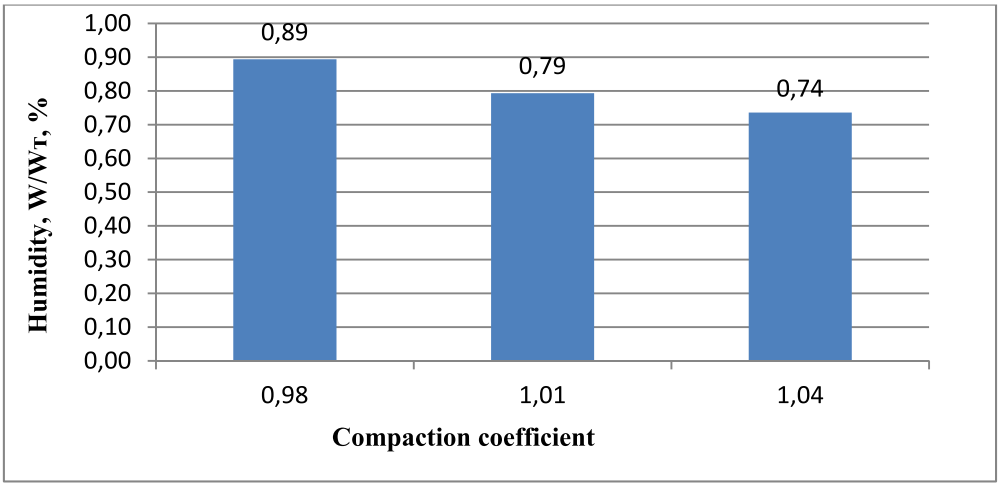

Fig. 5. Humidity of the loamy soil samples with varying density following the water saturation

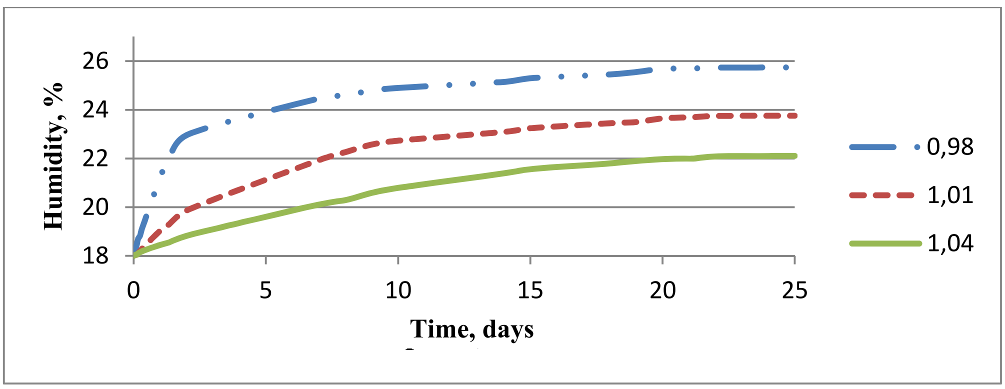

Fig. 6. Change in the humidity of the clayey soil samples with varying density

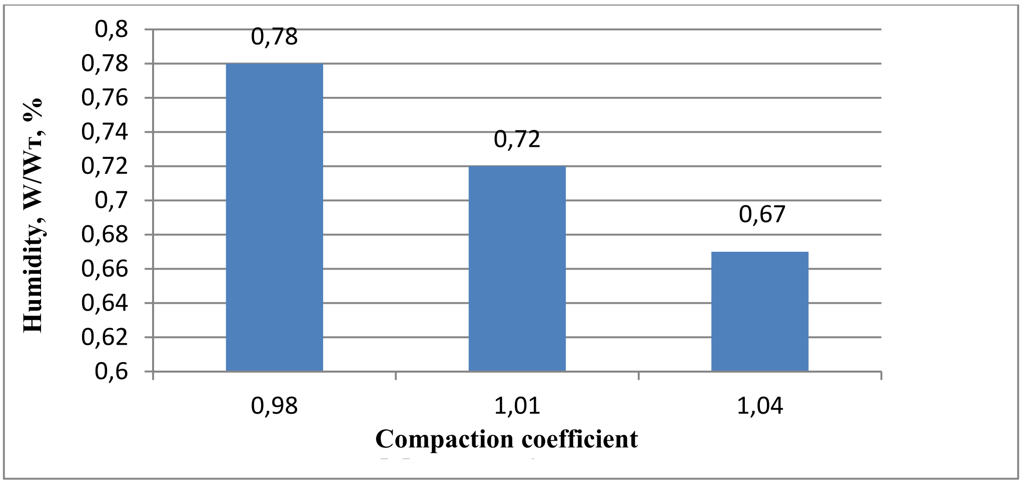

Fig. 7. Humidity of the loamy soil samples with varying density following the water saturation

The samples of both types were exposed to capillary water saturation with the humidity that corresponded with the optimal one. It should be noted that the experiment involving an increase in the humidity of the loamy soil was performed with the original humidity of 17.1 % of the optimal one till it had been saturated and the humidity of the samples had stopped rising. The compaction coefficient was found to have a significant effect on the rate of capillary water saturation, i.e. for the samples with the compaction coefficient K_h = 0.98 at the time of the saturation the humidity was 28.6 % (0.89 W_T), for the samples with K_h = 1.01 – 25.39 % (0.79 W_T), for the samples K_h = 1.04 is 23.55 % (0.74 W_T).

During the capillary water saturation of the clayey soils the humidity was rising starting with 18 % of the optimal one till they had been saturated and the humidity of the samples had stopped rising. For the clayey soil samples at the time of the saturation the humidity for various compaction coefficients was 25.74 % (0.78 W_T) for 0.98, 23.76 % (0.72 W_T) for 1.01, 22.11 % (0.67 W_T) for 1.04.

The residual deformation of the loamy soil samples at K_h = 0.98 and the humidity 0.8 W_T and more was over the acceptable level.

According to the results of the studies, the loamy soil sample gained the humidity 0.89 W_T at K_h = 0.98. Hence as the humidity of the subgrade soil reaches 0.8 W_T and more, the compaction coefficient of the subgrade soil should be increased. The compaction coefficient of 1.01 and more prevents the soil humidity from reaching 0.8 W_T.

The residual deformation of the clayey soil samples at K_h = 0.98 and the humidity 0.7 W_T and more was over the acceptable level. According to the results of the studies, the clayey soil sample gained the humidity 0.78 W_T at K_h = 0.98. Hence as the humidity of the subgrade soil reaches 0.7 Wт and more, the compaction coefficient of the subgrade soil should be considerably increased. The compaction coefficient of 1.04 and more prevents the soil humidity from reaching 0.7 Wт.

3. Measurements of the humidity and deformation of the soils in real road conditions. In order to identify the humidity and density of the soil as the residual deformations are increasing, studies in real road conditions were also performed. Humidity and residual deformation gauges were installed in the operating layer of the subgrade of a road under construction in the Tver region. Fine sand was used for constructing the subgrade [2, 16].

In two areas with the gauges the compaction coefficients of the subgrade soil were 0.99 and 1.03 respectively. The results for the humidity measured using the gauges are in Fig. 8.

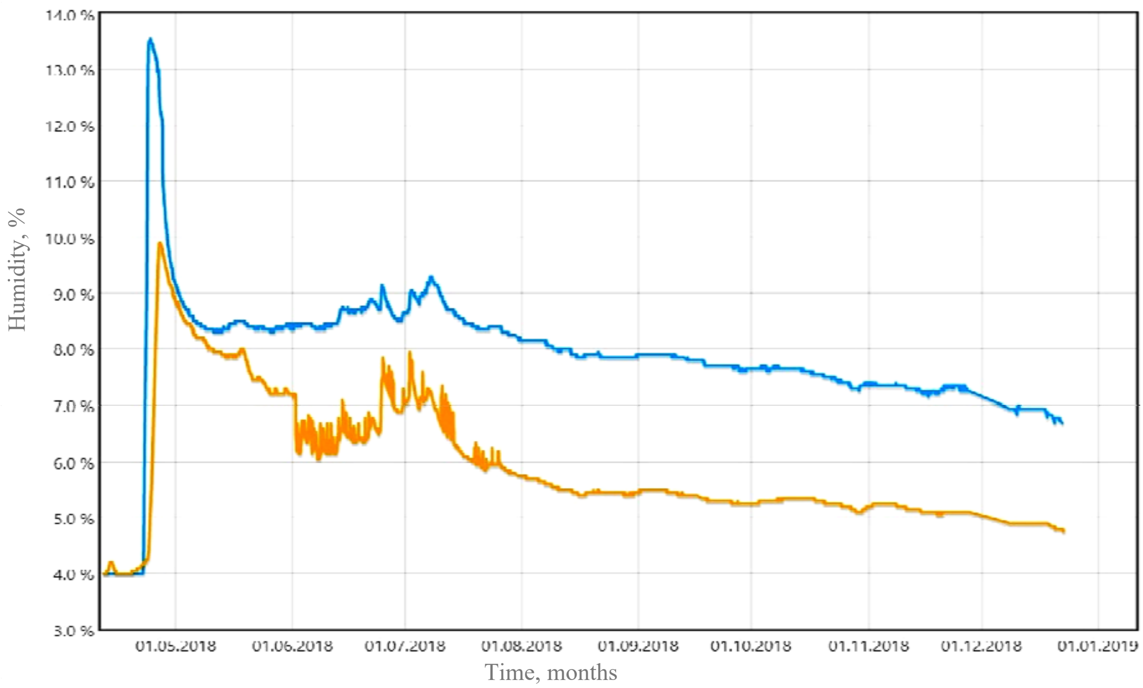

Fig. 8. Measurements of the humidity of the subgrade soil in the areas with varying compaction coefficients: — K_h = 0.99; — K_h = 1.03

According to the results of the studies, the subgrade soil with K_h = 0.99 throughout the calculation period gained 13.5 % of the humidity and that with K_h = 1.03 gained 10 % of the humidity.

The measurements of the residual deformations in the subgrade soil from 12.04.2018 to 10.01.2019 were the following: the area with K_h = 0.99 was 0.7 mm; the area with K_h = 1.03 was 0.2 mm.

Conclusions. As a result of the studies of the effect of the soil humidity on the residual deformations under the dynamic transport load impact, the total number of residual deformations and their intensity was found to be considerably dependent on the humidity.

The analysis of the data on the intensity of the capillary water saturation showed that changes in the humidity of binding soils considerably depend on the compaction coefficient (density) of soil, i. e. the higher is the compaction coefficient, the less prone it is to capillary water saturation. The tests in real road conditions showed that the higher the density of soil was, the less humidity and deformation it gained respectively.

Therefore it is necessary that the compaction coefficient should be increased in highway areas with a high likelihood of excessive humidity of subgrade soils throughout the calculated period.

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