Impact of repeated loads on saline soils of earth roadbed

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Abstract. The constant development of the road network in Uzbekistan, especially in widespread saline soils, necessitates increased attention to road structure strength. Since vehicles differ in weight and speed, it is obvious that the saline soil under the pavement is subjected to successive impacts of a load of different power and application force. Experimental studies to identify the patterns of changes in saline soils' physical and mechanical properties under repeated and short-term loads were conducted on a device specially designed by the authors of this study. The experiments were conducted on samples of sulfate and chloride-sulfate medium-saline heavy silty sandy loam, compacted at optimal moisture content to maximum density. When conducting the experiment, the impact duration of vertical load $P_{ver} = 0.15$ MPa on the sample was $t_{load} = 0.2$ sec, and the interval between the loads was 0.5 sec, the frequency of application was $f = 1.2$ Hz. The number of short-term load applications was recorded using an electric meter installed on the device. After a certain number of short-term cyclic load applications on the sample, its physical and mechanical properties were determined following the requirements of state standards (GOST). The results of the study show that with an increase in the number of cyclic and short-term load impacts on the sample, the following values increase: residual strain, density, and modulus of setting, relative swelling, swelling pressure, ultrasonic transmission rate, coefficient of filtration; while the porosity, coefficient of porosity, soaking, ultimate strength in uniaxial compression, the coefficient of dynamic viscosity, adherence, the angle of internal friction and the modulus of elasticity of soil decrease. It was determined that under the repeated impact of short-term loads in compacted saline soil, residual strains and short-term redistribution of stresses in the contact of soil and salt particles occur, which leads to a change in the physical and mechanical properties of soil.

1 Introduction

The constant development of the road network in Uzbekistan, especially in areas with saline soils, demands increased attention to the problem of the strength of road structures. The largest amount of saline lands in Uzbekistan is located in the Fergana region 77.7%, Bukhara region 70.1%, Khorezm region and the Republic of Karakalpakstan approximately

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70-80%, in Kashkadarya and Surkhandarya regions approximately 50-60%. In other regions, saline soils account for from 16 to 37% of the territory [1, 2].

In regions of Uzbekistan with different natural conditions, saline soils are different in composition and quantity. Salts $NaCl$, $Na_2SO_4 \cdot 10H_2O$, $MgSO_4 \cdot 7H_2O$, $MgCl_2 \cdot 6H_2O$, $CaCl_2 \cdot 6H_2O$, $NaHCO_3$, $Na_2CO_3 \cdot 10H_2O$, $CaCO_3$ и $CaSO_4 \cdot 2H_2O$, $CaCO_3$, and $CaSO_4 \cdot 2H_2O$ are most often found in the composition of soils. The content and amount of these readily soluble salts in soil determine their physical and mechanical properties.

The degree of soil salinization at the subgrade of roadways and its effect on the design indicators, the physical and mechanical properties of roads were comprehensively studied by foreign scientists [3-12]. However, the studies' analysis and the existing regulatory documents show that the calculated indicators and physical and mechanical properties of roads on saline soils given require elaboration and revision.

It should be noted that soil, in particular saline soil, as a subgrade base, is one of the most important elements of any structure, including pavement. Road clothes are considered durable if, under the influence of loads from moving vehicles, they maintain continuity and sufficient evenness for a given period. However, experience shows that the evenness of non-rigid pavements deteriorates during the highway operation (Fig. 1). Most of the pavement roughness accumulates due to the deformation of the subgrade soil under the influence of multiple traffic loads.

Fig. 1. Change in the evenness of the road surface during the road operation

When designing pavements, physical and mechanical properties are taken into account [13-19], namely, such characteristics of saline soils as density, moisture, porosity, settlement modulus, and the so-called design characteristics: soil elastic modulus E_{gr} , specific adherence C_{gr} and the angle of internal friction φ_{gr} . However, in the existing method for calculating road pavements, when setting design characteristics, multiple transport loads acting on the ground are not taken into account; this may cause deformation in the pavement. In this regard, the study of changes in saline soil properties under the influence of multiple transport loads is relevant.

N.N. Ivanov, A.K. Birulya, B.F. Babkov, A.M. Krivissky, M.V. Korsunsky, V.D. Kazarnovsky, N. Ya. Kharkhuta, G.S. Kanayan, V.M. Smirnov, A.S. Plipenko, D.A. Makhmudova, and others [1, 2] paid much attention to the study of the patterns of soil strains, in particular, of saline soil, underlying road clothes, under the influence of moving loads. As a result of the analysis of these studies, it can be assumed that the effect of short-term repeated loads causes more complex processes in soil (in comparison with the statistical effect of loading).

Studies of the soil behavior patterns under conditions that simulate the work of the subgrade soil under multiple transport loads on the pavement are few; and moreover, they were conducted mostly for sandy, clayey, and loess soils [20]. Such studies were not performed for saline soils.

The aim of the research is to study the patterns of changes in the physical and mechanical properties of saline soils under the influence of moving loads.

2 Methods

Laboratory studies were conducted to determine the effect of repeated and short-term loads on the physical and mechanical properties, including the strength and strain characteristics of compacted moderately saline sandy loamy soils of sulfate and chloride-sulfate salinization.

Laboratory studies were performed with moderately saline heavy silty sandy, loamy soils of sulfate and chloride-sulfate salinization sampled from the experimental road section "Reconstruction of the 4P33 Ulyanovo-Naiman highway (Gulistan-Gagarin 20 km)" (Fig. 2) located in the Syrdarya region of the Republic of Uzbekistan. The test soil had the following characteristics: the plasticity number $P_I = 5.0$, moisture content at flowability $W_{fl} = 27.5\%$; moisture content under rolling $W_p = 22.0\%$; maximum density at standard compaction $\gamma_{max} = 1710 \text{ kg/m}^3$ and optimal moisture content $W_{op} = 16.5\%$. To determine the above properties of soils, samples were prepared as follows.

Fig. 2. General view of the experimental section on the road "Reconstruction of the 4P33 Ulyanovo-Naiman highway (Gulistan-Gagarin 20 km)"

The saline soil was compacted in the ring of a GGP-30 shear device (Maslov–Lurie's design) at optimal moisture content up to a compaction coefficient of 1.0 on a hydraulic press by a short-term repeated impact of the load of 0.7 MPa at a total hold-up time of the sample under the load of 2 min. As a result, the process of soil structure formation during its compaction was modeled during the construction of the subgrade

Taking into account that (with modern road clothes) the pressure on the road surface from the car wheel $P = 0.6 \text{ MPa}$ decreases, in the roadbed soil, it ranges from 0.01 to 0.15 MPa depending on the thickness of the road surface. Therefore, the vertical load was assumed as $P_{ver} = 0.15 \text{ MPa}$, and it was applied to the sample cyclically. The application pattern of the cyclic load was as follows. A special arrangement was installed on the lever of the GGP-30 device, which transmitted vertical pressure to the ground; it allowed converting a constant static load into a short-term cyclic load.

During the experiment, the time of the vertical load impact on the sample was $t_{load} = 0.2 \text{ sec}$, and the interval between loads was 0.5 sec, the frequency of application was $f = 1.2 \text{ Hz}$. During one test, the loading mode remained constant. During the test, the loading mode and

changes in the axial strains of the sample were recorded in the range from 0 to 1000 loads after 100 cycles, in the range from 1000 to 10000 - after 1000 cycles, and then after 10,000 cycles. Depending on the magnitude of the short-term load, the test was considered complete when 1,000,000 loading cycles were applied to the sample or when the relative strain of the sample reached 15%.

3 Results and discussion

The physical and mechanical properties were determined on six compacted samples of saline soil after each of the above load cycles according to the requirements given in the corresponding standards (GOST). The experimental results are shown in Table 1. Soil density, porosity coefficient, relative swelling, swelling pressure, filtration coefficient, soaking, ultrasonic transmission, ultimate strength per axial compression, coefficient of dynamic viscosity, adherence, angle of internal friction, modulus of elasticity were determined.

Table 1. Influence of short-term and cyclic loading on the properties of moderately saline heavy silty sandy loams of sulfate and chloride-sulfate salinization at $W = W_{op}$, $K_{com} = 1.0$

Soil properties	Number of applications of repeated and short-term loads, $\sum N_p$							
	0	1	10^1	10^2	10^3	10^4	10^5	10^6
Soil density, γ , kg/m ³	1710	1711	1715	1720	1725	1731	1736	1737
Porosity, p %	0.360	0.355	0.353	0.352	0.351	0.349	0.346	0.345
Porosity coefficient, ξ	0.562	0.555	0.550	0.547	0.538	0.533	0.529	0.518
Relative swelling, h_n/h , %	1.4	1.4	1.5	1.6	1.7	1.75	1.78	1.8
Swelling pressure, P_{sw} , MPa	0.022	0.022	0.023	0.023	0.024	0.024	0.025 8	0.025
Filtration coefficient, K_f , 10 ⁻⁴ m/day	3.0	3.0	3.5	3.9	4.2	4.5	4.7	0.5
Soaking, min	16	16	15	14	13	12.7	12.3	12
Ultrasound velocity, m/ μ s · 10 ⁻²	0.043	0.043	0.043	0.043	0.435	0.043 7	0.043	0.044
Ultimate strength in uniaxial compression, MPa	18.5	18.5	18.0	17.5	17.0	16.5	16.3	16.0
Dynamic viscosity coefficient, η · 10 ⁹ , Pa·s	2.8	2.8	2.7	2.6	2.5	2.3	2.5	2.2
Adherence, C_{gr} , MPa	0.055	0.054	0.052	0.050	0.048	0.046	0.044	0.042
Internal friction angle, ϕ_{gr} , degr.	28	27	26	25	24	23	22	21
Elastic modulus, E_{gr} , MP	82	80	79	78	77	76	74	73

The laboratory experiments conducted (Table 1) show that with an increase in the amount of cyclic and short-term load impact on the sample, the density, relative swelling, swelling pressure, ultrasonic transmission rate, filtration coefficient and porosity, coefficient of porosity, soaking, ultimate strength under uniaxial compression increase, while the

coefficient of dynamic viscosity, adherence, the angle of internal friction and the modulus of elasticity of soil decrease. This is explained by the fact that under repeated impacts of short-term load in compacted saline soil, residual strains and short-term redistribution of stresses in the contact of soil and salt particles occur, which leads to a change in the physical and mechanical properties of soil.

Comparison of the experimental results (Table 1) with the results of other authors, in particular V.M. Smirnov for sandy soils [21], A.S. Pilipenko for clayey soils [22], and D.A. Makhmudova for loess soils [23, 24] indicates that the adherence and the angle of internal friction decrease with an increase in the number of load applications; that is, the results show their convergence.

4 Conclusions

As a result of the conducted scientific research, the following conclusions can be drawn.

1. When assessing the evenness of non-rigid road surfaces during the highway operation, it is necessary to consider the traffic intensity, i.e., the impact of multiple traffic loads on the saline soil of the subgrade.

2. With repeated application of short-term load to saline soil of the subgrade (other things being equal), its physical and mechanical properties change; some property indicators increase, while others decrease with an increase in the number of cycles.

3. The change in the physical and mechanical properties of saline soils under cyclic loads is explained by the fact that under the repeated impact of short-term loads on the compacted saline soil, residual strain and short-term redistribution of stresses in the contact of soil and salt particles occur, which leads to a change in soil properties.

4. At a large number of short-term load applications, the accumulation of residual strains of compaction attenuates. The beginning of the attenuation can be called the "damping threshold".

5. When designing the road pavement structure, it is advisable to use the strength and strain characteristics of saline soils, considering the impact of short-term and repeated loads.

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