The role of soil compaction in ensuring subgrade stability in various climatic conditions

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ABSTRACT

This article presents the results of a study to determine the maximum density and optimal moisture content of soils, taking into account the patterns of the water-thermal regime of the subgrade, the sources of wetting the subgrade and the entire road structure, and their seasonal water-thermal regime.

Keywords: roads, subgrade, water-thermal regime, moisture content, water accumulation, modulus of elasticity, standard compaction, maximal density, optimal moisture content.

Introduction. The water-thermal regime (WTR) of the road structure significantly affects the strength and frost resistance of the road structure and, ultimately, the degree of pavement roughness. The most significant seasonal changes in moisture content and temperature occur in the subgrade.

The annual cycle of the subgrade WTR includes four main characteristic periods (Fig. 1):

- 1) pre-winter period - the initial accumulation of water in autumn;
- 2) frost period - freezing, redistribution, and accumulation of water in the subgrade in winter;
- 3) spring period – subgrade thawing and soil waterlogging in spring;
- 4) summer period - subgrade drying in summer.

In the unfavorable (for the road services) period of the greatest weakening of the road structure, its strength must meet the requirements of road traffic.

The actual moisture content of the subgrade soil of operated roads can be assessed as a result of direct observations of the WTR of the subgrade. However, this moisture content will not always correspond to the calculated value.

In view of the temporal (per season and per year) variability of subgrade soil moisture content and the need to assess the strength of the road structure at a given level of reliability, the calculated moisture content in soil is determined by a probabilistic method.

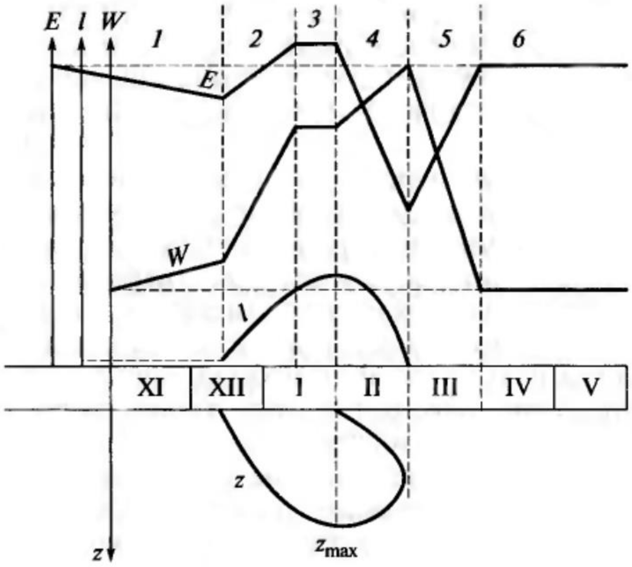

Fig. 1. Seasonal changes in the water-thermal regime of the subgrade: 1 - pre-winter period; 2 and 3 – frost periods of water accumulation and winter equilibrium state, respectively; 4 and 5 - periods of spring thawing and drying of soil, respectively; 6 - summer equilibrium state; I-V, XI, XII - months of the year; E is the modulus of elasticity of the road structure; l is the frost heaving; W is the relative moisture content of soil; Z is the freezing depth

The density and moisture content of the subgrade are of great importance for various climatic conditions, the type of soils, their uniformity, grain-size and mineralogical composition, and wetting conditions. The modulus of elasticity of the subgrade layers and the strength and service life, density and other operational qualities of roads largely depend on these indicators. Therefore, the issue of subgrade soil compaction has been and is being given special attention by scientists and specialists worldwide.

To clearly predict how the strength of domestic roads can be increased, especially in the second road-climatic zone, where most of the subgrade is filled with cohesive soils, it is necessary to at least briefly imagine the essence of the physical processes occurring in soil.

The soil strength, determined by internal friction and cohesion, and its deformability, characterized by elastic deflection, depend on the ratio of three phase components per unit volume: the soil skeleton, water and air that fill the soil pores, and on the dispersion of soil, its chemical and mineralogical compositions. Water enveloping mineral particles (film water) is located in the zone of action of intermolecular forces, which brings its properties closer to the properties of solid elastically viscous bodies. The higher the moisture content of soil, the greater the thickness of the films, the greater their deformability and the lower the strength. The modulus of elasticity of mineral particles is several orders of magnitude greater than the modulus of elasticity of films; therefore, an increase in the density of the soil skeleton and a decrease in moisture content leads to a decrease in the deformability of soil.

Methods. The climatic conditions of most regions of Uzbekistan determine the cyclical pattern in the moisture content-density change, and, consequently, the strength and deformation parameters of the soil foundation of the road structure. The density of soils in the annual cycle of the water-thermal regime depends on the ratio of the values of autumn soil swelling, winter heaving, spring settlement of the ground, and summer shrinkage. Theoretical calculations performed using the theories of water accumulation allow us to assert that there is a tendency for soils to acquire a so-called "stable" density over a long period. The intensity of the density change is not constant and is determined by a complex of road-climatic and soil-hydrological conditions. If the initial density of soils is close to stable, the processes of compaction-decompaction can be mutually compensated during the year: fluctuations in soil density and related fluctuations in roughness will only have a seasonal character, and the degree of accumulation of residual strains will be determined not by uniformity, but, consequently, by the degree of density of the subgrade. If the initial density is higher, then it practically does not change, and only in some cases, the moisture content increases.

Thus, it is clear that if the initial density differs significantly from the "stable" density, the seasonal density fluctuations will not be mutually compensated until the ground density approaches the stable density. In this case, the high initial density (high compaction) due to the high uniformity of soil in all its physical and mechanical parameters will ensure a minimum of residual strains. If the initial density is below a stable value, a significant amount of residual strains will be determined by non-uniform density fluctuations in the annual cycle.

The analysis of the results of theoretical studies performed, the data of experimental work in a laboratory setting and during empirical construction make it possible to recommend compaction coefficients that exceed stable values by 0.05 $y_{\text{тах}}$, as standard values; here stable values are determined using many years of experience and calculated prediction of soil density-moisture content in the annual thermal water cycle. Forecasting was based on approximating dependencies of discrete factors, having eliminated random factors that affect the result of forecasting.

Considering the effectiveness of high soil compaction, due to a decrease in the cost of pavement repairs during road operation, it is advisable to compare it with the design of pavement, characterized by an average service life actually observed in real conditions of road construction and operation.

In turn, the currently available data on the degree of possible soil decompaction allow us to state that the compaction of subgrade soils up to K_y = 1.02 leads to the possibility of increasing the estimated service life till overhaul to 11 years. It is reliable to assume that at a density of 1.05, the estimated period can reach 16 or more years.

Approximately every fourth kilometer of all paved roads is extremely worn out. Obviously, the situation cannot be corrected by layering asphalt concrete on an insufficiently compacted base. However, traffic still moves on these roads, even if they are only 30,000 km long.

Therefore, for a general improvement in the quality of the highway, the roughness and strength of its pavement, the prevention of the heaving, etc., it is advisable to slightly increase the standard values of the compaction coefficient of the subgrade, which is possible to realize during the construction of a new road or in the process of reconstructing individual sections of automobile roads. During the tests, samples were taken from the highway section 4K546 Nurbulok k.-Boshkuduk k.-Ulus k., 1-2 km" (Figs. 2, 3).

Fig. 2. Sampling during the construction of highways "4K546 Nurbulok k.-Boshkuduk k.-Ulus k.

Fig. 3. Groundwater level measurement

The required soil compaction coefficients relative to their maximum density were obtained on the Proctor ASTMD 698 compacting device [2], using a cylinder with a diameter of 100 mm and a height of 115 mm by ramming with a 4.5 kg weight falling from a height of 457 mm, 125 blows (Figs. 4, 5).

Fig. 4. Testing

Fig. 5. Test preparation

The **results** of the study to determine the maximum density and optimal moisture content of the soil skeleton are given in Table 1 and Fig. 6.

№	Determination of density		Determination of moisture content			Densi ty of dry
	Weight, g		№ of glass for	Weight g	Moisture content w, %	

	Forms m_c	Forms with compacted soil m_i	Compacted soil $m_i - m_c$	Soil density, g/cm^3	weighing	of empty glass	Glass with wet soil	Glass with dry soil	Absolute	Average	soil, g/cm^3
1	3380	5110,0	1730,0	1,85	109	21,12	61,32	58,22	8,4	8,4	1,70
					185	21,1	51,36	49,0	8,5		
2	3380	5195,0	1815,0	1,94	102	21,35	56,61	53,3	10,4	10,6	1,75
					184	21,15	62,02	58,05	10.8		
3	3380	5245,0	1865,0	1,99	125	22,5	50,99	47,88	12,3	12,2	1,78
					181	21,55	55,2	51,57	12,1		
4	3380	5300,0	1920,0	2,05	108	22,3	52,12	48,3	14,7	14,3	1,79
					22	22,05	58,72	54,22	14,0		
5	3380	5320,0	1940,0	2,07	3	21,79	48,06	44,41	16,1	16,2	1,78
					4	21,9	62,04	56,4	16,3		
6	3380	5330,0	1950,0	2,08	7	21,7	48,59	44,42	18,4	18,3	1,76
					8	21,36	45,85	42,07	18,3		
7	3380	5285,0	1905,0	2,03	2	21,85	49,85	45,13	20,3	20,3	1,69
					11	23,06	52,10	47,21	20,4		

Table 1. Test results.

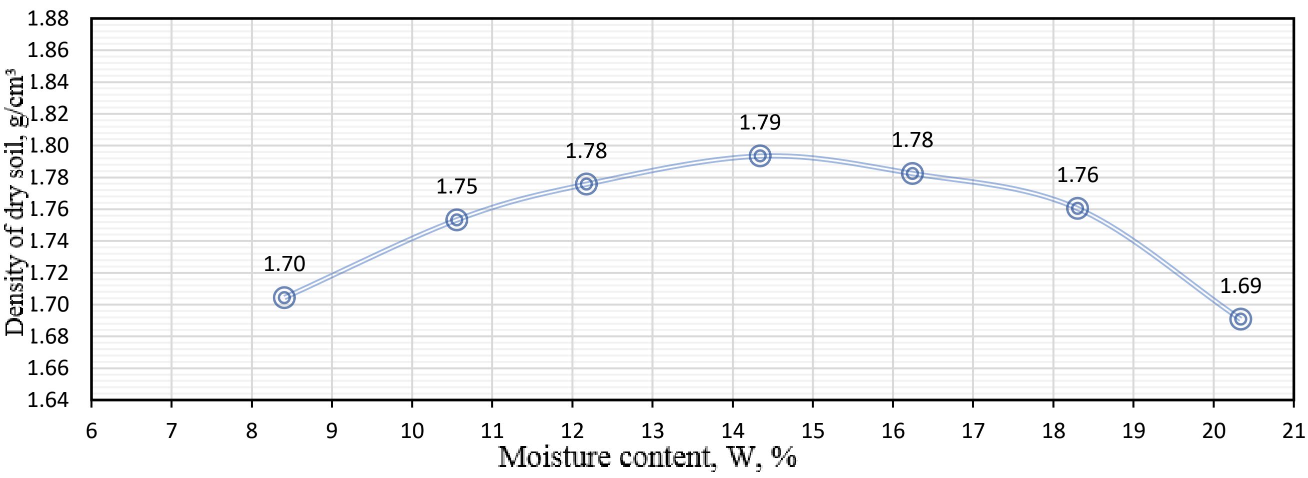

Fig. 5. Graph of dependence of changes in soil density on moisture content (*Maximum soil density 1,79 g/cm^3 at optimal moisture content 14,3%*).

In this case, the density of soil, depending on these factors, can play a different role. For example, under conditions of complete filling of the pores of clayey soil with water, a regular decrease in heaving is always observed as its initial density increases.

Conclusions. Thus, if the soils of the roadbed initially had a very high density, but the appropriate waterproofing, cutting off sources of wetting, hydrophobization of soils, etc. were not provided for, then over time they can again decompact under the influence of seasonal freezing-thawing processes and re-acquire heaving properties. It should be recognized that the suggestions to increase the initial density of soils of the roadway to the values of 1.03-1.05 obtained during the Proctor test are scientifically justified and correct in their essence. They are correct under conditions of simultaneous preventive measures aimed at maintaining soil moisture content below critical values. The excess of moisture content can again lead to the development of heaving processes and, accordingly, to soil decompaction, i.e., to the measures aimed at ensuring complete and high-quality drainage and preventing soil wetting in the active zone of the subgrade.

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