Design characteristics of road embankments made of sandy soils

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Abstract. Sandy soils are widespread all over the world, including in Uzbekistan, and they are widely used in the construction of highways. Therefore, several regulatory documents have been developed that normalize their design characteristics.
However, in the existing regulatory documents, the design characteristics of sandy soils of road embankments of highways used in the design of road coverings (modulus of elasticity E, angle of internal friction φ, specific adhesion C) are not normalized depending on the degree of compaction, calculated humidity and the content of dusty and clay particles in such soils. To solve these problems, special laboratory and field studies were conducted, the results of which are given in this article.

1 Introduction

Sandy soils are widespread in the conditions of Uzbekistan and are very suitable for the construction of various structures, including highways because they do not compress much under load. They have significant shear resistance and resistance to the effects of weather and climatic factors.

The study of sandy soils was carried out by scientists such as Das B. M. [1], Price D. G. [2], Knappett J. [3], Dobrov E.M. [4], Salik T. [5], Kayumov A.D., [6], Arlery M. [7], Artykbaev D. J. [8], Drumm E. C., Smirnov V.M. [10]. As a result of their research on the use of sandy soils in construction, several documents have been developed, such as STATE STANDARD 8736-93 [11], STATE STANDARD 25100-2011 [12], STATE STANDARD 87-2009 [13].

It should be noted that the majority territory of the Republic of Uzbekistan is occupied by sandy soils. In this regard, such soils are often used to construct highways in the Republic of Karakalpakstan, Bukhara, Navai, Surkhandara, and Ferghana regions. The example in Fig. 1 shows the A-380 highway built in sandy deserts in the Bukhara region of Uzbekistan.

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Fig. 1. The A380 highway in the Bukhara region of Uzbekistan

Regulatory documents related to the design and construction, such as SHNK 2.05.02-07, SHNK 3.06.03-08, the soil compaction coefficient of the working layer of highways, including sandy ones, are proposed in depth within 0.95-0.96. An analysis of the literature shows that these coefficients result from studies conducted before 2007. At the same time, the study of the number of cars passing per day shows that from 2007 to the present, the traffic intensity on the highways has increased significantly; in addition, the load on the car's axle has increased to 13 tons.

It should be noted that in the current regulatory documents, such as MCS 44-2008 and MCS 46-2008, their mechanical properties are used for the design of the construction of roadways built in the roadbed of sandy soils, such as the angle of internal friction φ, adhesion C and modulus of elasticity E. In these documents, the indicated indicators of sandy soils are given for conditions of full filling with water, and the corresponding soil compaction coefficient is not indicated.

It should be noted that in the conditions of Uzbekistan, the calculated humidity of sandy soils ranges from 0.50-0.65 Wt. At the same time, assigning the calculated characteristics at humidity equal to the total moisture capacity creates several problems for designers when designing road surfaces in sandy soils. This, in turn, leads to the destruction of road clothes before their service life. Therefore, one of the urgent tasks is considered to be the study of these problems, i.e., the purpose of the study is to assign calculated indicators for sandy soils depending on their compaction coefficient, calculated humidity, and the content of dusty and clay particles, as well as to develop methodological recommendations for their determination.

2 Methods

To clarify the above-mentioned indicators of sandy soils, special experimental studies were conducted in laboratory and field conditions on various highways of the Surkhandarya regions of Uzbekistan, where sandy soils are widespread.

It is noted above that for calculating the construction of road surfaces following the normative characteristics of soils, including sandy ones, the angle of internal friction φ, adhesion C, and modulus of elasticity E are important. To determine these values, in general, you can use the following dependencies:

$$\left.\begin{aligned} E &= f_1(K_y, W_p, A) \\ C &= f_2(K_y, W_p, A) \\ \varphi &= f_3(K_y, W_p, A) \end{aligned}\right\} \qquad (1)$$

where E is the modulus of elasticity, MPa; C is adhesion, MPa; φ is the angle of internal friction, deg; Ku is the compaction coefficient; Wp is the calculated humidity; A is the content of dust and clay in sandy soils, %.

To establish the dependence (1) for a given soil composition, it is necessary, first of all, to determine the compaction coefficient (as is customary in road design); after that, it is necessary to determine the values of E, C, and φ in laboratory and field conditions at certain values of A.

The initial soil for conducting experiments in laboratory conditions were sandy soils selected from existing highways 4P-100b Termiz-Gulkhovuz-Zharkyrgan, 10-km and 4P-23m Namuna-Lemonaria-Kaptarkhona, 4-km. The granulometric composition of sandy soils is shown in Table 1.

Table 1. Granulometric composition of the studied soils

Ground number	Sand residue in a sieve, gram					The name of the soil, according to STATE STANDARD 8735-88 and STATE STANDARD 8736-93
	2.5	1.25	0.63	0.315	0.16	
1	4.95	6.90	62.75	24.05	74.01	medium-sized sands
2	0.04	0.21	1.87	16.04	57.66	fine sands

3 Results and Discussion

It is known that the mechanical properties of sandy soils primarily depend on its density. Therefore, to determine the characteristics of sandy soils, it is necessary to first establish the value of the household density of the roadbed in depth.

The density and mechanical properties of sandy soils of the roadbed were studied in 2007-2022 on existing operated roads built in the 1960 s and 1970 s. Data on soil moisture and density during construction are not known.

During the survey, more than 50 pits were laid up to 1.2 m deep from the bottom of the pavement. The density of sandy soils was determined at a depth of 0.1, 0.3-0.4, 0.5-0.6, 0.8-0.9, and 1.0-1.2 m with the help of a specially designed and manufactured device [19], followed by control by a cutting ring with a volume of 5 x 10-4 m3, humidity - by weight method. The compaction coefficient of these soils in laboratory conditions was determined according to STATE STANDARD 22733-2002 [15].

Figure 1 shows the distribution of the average value of the compaction coefficient, the coefficient of variation, and the accuracy index of the soil by the depth of the embankment according to the surveys of 2007-2022. It can be seen that the coefficient of compaction decreases with increasing depth of the embankment. The coefficient of compaction of the 0.2÷0.3 m thick soil layer under the pavement is 0.98÷1.0. In 2007-2022, the fluctuations of these values from the average did not exceed 7-10%.

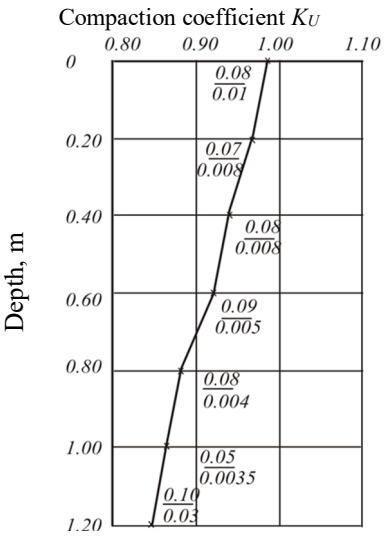

Fig. 2. Distribution of the average value of the soil compaction coefficient at the depth of the embankment, according to the survey 2007-2022. Figures in curves: numerator-coefficient of variation; the denominator is an indicator of accuracy

The modulus of elasticity of sandy soils is determined on the device PDU-MG4. The tests were carried out following the regulations. In the field, the strength characteristics were determined by a single-bone rotational slice device [17], for control they were compared with the values of the angle of internal friction and specific adhesion obtained in laboratory conditions by the Maslov-Lurie device when testing soil monoliths selected from the pit.

After statistical processing, generalized and averaged values of the modulus of elasticity, adhesion, and the angle of internal friction of sandy soils of medium size and fine, determined in laboratory and field conditions depending on the compaction coefficient (K_u = 0.94, 0.96; 0.98, 1.0), calculated humidity (Wr= 0.50, 0.55, 0.60, 0.65 Wt) and the content of dusty and clay particles in the soil (A = 0, 5, 8%), taking into account the coefficients of variation, their calculated values were recommended.

Table 2 shows the calculated characteristics of medium-sized sands from the compaction coefficient K_u = 0.96, the content of dusty and clay particles A = 0.5, and 8%, and the calculated humidity W_t = 0.50, 0.55, 0.60, and 0.65.

Table 2. Design characteristics of medium-sized sands

Compaction coefficient K_u	The content of dusty and clay particles A, %	Design characteris-tics	Calculated humidity, fractions of W_t			
			0.50	0.55	0.60	0.65
0.96	0	*E, MPa*	109.0	103.0	97.0	95.0
		φ, grad.	42.6	42.39	42.00	41.58
		C, MPa	0.019	0.0176	0.0165	0.0154
	5	*E, MPa*	105.0	101.0	96.0	94.0
		φ, grad.	41.42	41.13	41.38	40.59
		C, MPa	0.0198	0.0184	0.0171	0.016
	8	*E, MPa*	98.0	91.0	85.0	79.0
		φ, grad.	41.21	40.52	40.41	40.25
		C, MPa	0.021	0.020	0.0189	0.0176

Based on the static processing of field and laboratory studies, empirical dependences of the calculated characteristics of sandy soils on the compaction coefficient (K_u), calculated humidity (W_r), and the content of clay and clay particles (A) are proposed:

$$E = \Delta E_W\,(1.06 - 0.06\,W_r) + \Delta E_u(K_u - 2) - \Delta E_A(A - 0.4) \quad (1)$$

$$C = \Delta C_W\,(1.18 - 0.08\,W_r) + \Delta C_u(K_u - 1.08) - \Delta C_A\,(2000A - 1850) \quad (2)$$

$$\varphi = \Delta\varphi_W\,(1.01 - 0.07\,W_r) + \Delta\varphi_u\,(0.083K_u^2 - 1.083K_u + 1.042) - \Delta\varphi_A(A - 0.05) \quad (3)$$

where ΔE_W=107 MPa; ΔE_u=2 MPa; ΔE_A=1.45 MPa; ΔC_W=0.017 MPa; ΔC_u=0.0013 MPa; ΔC_A=0.002 MPa; $\Delta\varphi_W$=0.017 grad; $\Delta\varphi_u$=0.48 grad and $\Delta\varphi_W$=0.19 grad dependent coefficients, respectively, of the coefficient of consolidation, settlement humidity and the content of clay, silt, and sand particles of medium size.

Also, the corresponding formulas for determining the design characteristics for fine sands were obtained after processing field and laboratory work.

4 Conclusions

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

1. Due to the increase in traffic intensity on the highways of the Surkhandarya region of Uzbekistan from 2007 to 2022 by several times and the calculated axle load up to 13 tons, there is an increase in density-the compaction coefficient of sandy soils from 0,95-0,96 to 0,96-1,00, i.e., on average 0,04. This increase is not considered in the current regulatory documents on the norms of density and design characteristics of sandy soils.

2. As a result of laboratory and field work, an experimental method for determining the calculated characteristics of the working layer of sandy soils has been developed, and empirical dependences for their determination have been obtained.

3. The conducted experimental studies show that an increase in the compaction coefficient leads to an increase in the modulus of elasticity, cohesion, and the angle of sandy soil's internal friction. An increase in the calculated moisture content leads to their decrease.

4. An increase in the content of dusty and clay particles leads to an increase in adhesion and a decrease in the elastic modulus and the angle of internal friction.

5. When designing road surfaces, using the proposed design characteristics of sandy soils leads to an increase in the service life of the road.

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