Method for Determining the Maximum Density and Optimal Moisture Content of Coarse-Grained Soils by the Proctor Method

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ABSTRACT

This article presents the results of a study to determine the maximum density and optimal moisture content of coarse-grained soils with sandy aggregates using a large-size Proctor test equipment. Recommended values of maximum density and optimal moisture content depend on the size of the fraction.

Keywords: commercial banks, level of capitalization, resource base, capital, financial stability, authorized capital, subordinated debt obligations

Introduction. One of the main factors determining the reliability and performance of roads is the stability of the entire road structure. In this case, the soil stability criterion is its density. The sequence of performing the calculation of pavement begins with the clarification of the road-climatic zones of the territory and the design characteristics of soil. Soil density norms in force in Uzbekistan are differentiated depending on the construction area (road-climatic zone), the location of soil along the height of the embankment and the conditions under which it is exposed to various natural and climatic factors. The regulatory document VSN 55-61, for the first time developed in 1960, and its modern standards were subsequently refined and developed (VSN 55-69, SN 449-72, SNiP 2.05.02-85, KMK 2.05.02-96, ShNK 2.05.02 -07, etc.).

The standards set the minimum allowable requirements for soil density, which ensure the stability of road structures, in particular, their necessary performance.

In connection with the growth of traffic density, a significant increase in the number of heavy vehicles in traffic, increased requirements for the evenness of the pavement, and the strength of the road structure, it became necessary to reconsider the problem of the stability of the subgrade and pavement in order to summarize the results of theoretical studies and the results of a survey of the existing road network.

The analysis of these data confirmed the current level of existing standards and showed that the previously developed and further improved physical theory of stability of the road structure, in particular the subgrade, could and should be the basis for normalizing the density of soils. This theory is based on the concept of the soil as an energy system capable of resisting external influences. The need to improve and clarify existing norms was also identified.

Methods. Special studies were conducted to clarify the norms of soil density in the upper layer of the embankment, located directly under the road pavement in the subgrade, and the density at the very base of the pavement, erected from sandy and coarse-grained soils. Experiments were performed in laboratory on the Proctor test equipment during the construction and inspection of roads under various conditions in the regions of Uzbekistan. When conducting experimental studies, coarse-grained soils of various roundness and grain sizes were used.

Coarse-grained soils are a kind of detrital rocks formed during the deposition and accumulation in air or water of materials of physical, chemical, and physicochemical weathering of the original rocks [4], in which the weight of particles larger than 2 mm is more than 50%.

The wide distribution of coarse-grained soils during the construction of roads, and the absence of the actual values of the characteristics of coarse-grained soils in the regulatory documents for the design of pavements [1], determined the need for additional research in this area. Proceeding from this, the main goal of this study is to refine the calculated values of coarse-grained soils.

The conducted studies show that for embankments of roads being built in desert and desert-steppe geographical zones of Uzbekistan in an arid climate and widespread dune sands with varying degrees of mobility, the minimum required compaction coefficient K_c of the uniformly graded sands should be assigned in accordance with Table 1.

As seen from Table 1, the thickness of the upper, denser layers of the embankment is higher primarily for roads with capital-type pavements (roads of categories I-II). This is due to the high sensitivity of uniformly graded sand to the dynamic impact of moving vehicles and its ability to additional compaction as a result of such an impact.

Table 1. Compaction coefficient of uniformly graded sands

Part of the embankment	**Depth of the layer from the pavement surface, m**	**K_c of uniformly graded sands in road embankments, categories**		
		I-II	**III**	**IV-V**
Upper	Up to 1,5	1,00	0,98	0,97
Lower	More than 1,5	0,98	0,97	0,95

To reduce or eliminate significant and uneven subsidence of capital-type pavements, the thickness of this layer was increased to 1.5 m (previously it was 0.8 m).

Coarse clastic soils, according to existing regulatory documents, depending on the size of the fragments and the type of aggregate, are divided into six classes (Table 2).

Table 2. Classification of coarse-grained soils

Soil type	**Soil class**	**Particle content in % of total weight of dry soil**
A. Coarse-grained soil on sand aggregate		
Soil is blocky (with the predominance of rounded stones-boulders)	I	The weight of stones larger than 200 mm is more than 50%
Crushed stone soil (with a predominance of rounded pebble particles)	II	The weight of particles larger than 10 mm is more than 50%
Medium fine soil (with predominance of rounded gravel particles)	III	The weight of particles larger than 2 mm is more than 50%

B. Coarse-grained soil on clay aggregate		
Soil is blocky (with the predominance of rounded stones-boulders)	IV	The weight of stones larger than 200 mm is more than 50%
Crushed stone soil (with a predominance of rounded pebble particles)	V	The weight of particles larger than 10 mm is more than 50%
Medium fine soil (with predominance rounded gravel particles)	VI	The weight of particles larger than 2mm is more than 50%

Note: *When the proportion of clastic particles larger than 2 mm in soil is from 20 to 50% by weight, the soil should be referred to clay soils with the addition of the word "gravelly" for rounded particles, or "rubble" for unrounded particles.*

It should be noted that crushed stone-sand and crushed stone-gravel-sand mixes (hereinafter referred to as ready-made mixes) and crushed stone used for laying foundations must comply with the requirements of the Interstate Standard GOST R 70456-2022 [2] and be manufactured according to the technological regulations approved by an enterprise-manufacturer.

According to GOST R 70456-2022, crushed stone, depending on the function performed during the construction of foundations, is divided into main and wedged crushed stones. Crushed stone of fractions 40-80 or 80-120 mm is used as the main one. As wedged stones for fraction 40-80 mm, crushed stone of fractions 5-10 and 10-20 mm (a mix of fractions of 5-20 mm), ready-made mixes of C6, C11 are used; for fractions of 80-120 mm, crushed stone of fractions of 5-20 and 20-40 mm (a mix of fractions of 5-40 mm), ready-made mixes of C5, C1 [6] are used.

During the tests, samples were taken from the highway "4N-513 Chunkaymish, 10 km" (Fig. 1, 2).

Fig. 1. Nurabad district, road construction “4N 513 Chunkaymish".

Fig. 2. Soil selection and preparation.

At present, the required degree of compaction of large-clastic natural and man-made soils, including crushed stone-sand and crushed stone-gravel-sand mixes and crushed stone in the working layer is established based on the results of standard and test compaction. The degree of compaction of the subgrade and the base of coarse-grained, clayey, "gravelly" or "rubble" soils, and crushed stone-sand and crushed stone-gravel-sand mixes and crushed stone with a grain size of 20 mm is characterized by the ratio of the volumetric weight of the soil skeleton to the volumetric weight of the soil skeleton, obtained using the ASTMD 698

Proctor device (Fig. 2).

For coarse-grained soils and mixes with a maximum size of crushed stone 40 mm and a content of 20-40 mm fraction up to 30% in the mix, the same forms, methods, and compaction modes can be used as for a mix with a maximum grain size of 20 mm. For mixes with a maximum size of 80 and 120 mm, a correction is introduced for particles larger than 20 mm: $К_{80}$=1,07 $К_{20-40}$ and $К_{120}$=1,10 $К_{20-40}$.

The required compaction coefficients of coarse-grained soils relative to their maximum density were obtained in the Proctor compaction device [2], using a cylinder with a diameter of 100 mm and a height of 115 mm by tamping with a 4.5 kg weight falling from a height of 457 mm with 125 blows (Fig. 3, 4).

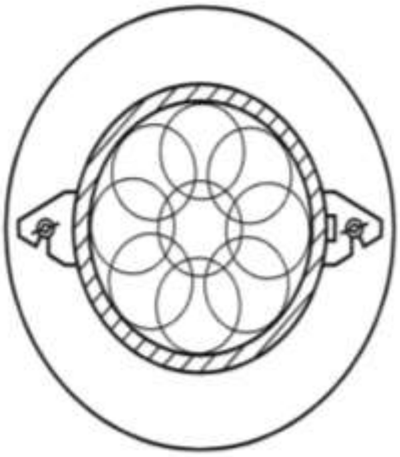

Fig. 3. Scheme of blows during. compaction.

Fig. 4. Testing process.

The results of the study to determine the maximum density and optimal moisture content of the skeleton of coarse-grained soils in bulk are given in Table 3 and Fig. 5

Table 3. Test results.

№	**Soil moisture content, %**	**Soil density, g/cm³**	**Dry soil density, g/cm³**
1	1,7	2,18	2,14
2	2,5	2,20	2,15
3	**3,44**	**2,25**	**2,18**
4	4,3	2,24	2,15
5	5,2	2,21	2,10

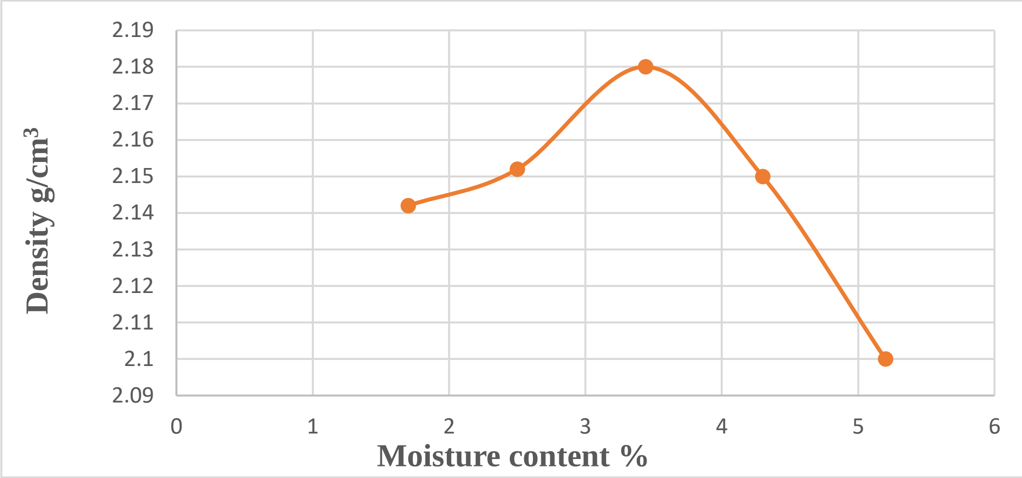

Fig. 5. Graph of dependency of the change in coarse-grained soil density on moisture content.

Conclusions. As a result of a survey of existing roads built from coarse-grained soils, the following values of the compaction coefficient were obtained:

- for rounded ones: for capital types of paving $К_с$ =0,98, for lightweight type $К_с$ =0,96, for transitional types $К_с$ =0,94;

- for slightly rounded and non-rounded ones: for capital types of paving $К_с$ =1,00, for lightweight type $К_с$ =0,98, for transitional types $К_с$ =0,96.

At the same time, it should be noted that the foundations erected from these materials must have the required compaction coefficients throughout the entire thickness of the foundation.

- mixes for foundations (continuous granulometry) – 1,26;

- mixes for foundations (discontinuous granulometry) – 1,22.

The compactability of coarse-grained soils, as well as "gravelly" or "rabble" soils, practically depends little on their moisture content. It is recommended to compact soils at a moisture content of no more than 1,1-1,2 of the optimal one obtained in the Proctor device.

The recommended compaction factors are approximately acceptable and, with appropriate justification, can be changed in one direction or another based on the results of trial rolling.

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