Laboratory measurements of dispersed soils as construction materials for railway embankments

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Abstract. Compacted construction sand - dispersed soil - is the main construction material for the construction of railway embankments. The supplier is obliged to present the main physico-mechanical properties of the building material not in free-flowing state, but in a compacted state, in which the material will work as part of railway embankments. A major problem in laboratory dispersed soil application tests is the inability to keep the specimen in its compacted state before placing it in a shear instrument or stabilisation meter. Hence, laboratory testing of dispersed soils can only be carried out in the bulk state and therefore the question of directly determining the physical and mechanical characteristics of building materials at their maximum density remains open. Methodology of direct testing of compacted samples in a single plane shear apparatus for determination of strength properties was developed and tested by the authors of the article, and also the methodology of determination of deformation properties by indirect way was suggested for preliminary evaluation of soil suitability as a building material for construction of railway embankments.

1 Introduction

A substantial amount of building material is required for the construction of railway embankments. Compacted building sand is usually used for this purpose, but other local soils such as gravel and sand or gravel and clay deposits can also be used. Considering the inevitable increase in the release of plastics into the environment [1] work is also underway to investigate artificial blends of sand and plastics or rubbers [2].

The building material supplier shall present its basic physical and mechanical characteristics, but not in bulk but in the compacted state in which the building material will operate as part of railway embankments. Provided physical and mechanical characteristics are not only necessary for analytical calculations of the stability of embankments or retaining walls but are particularly important for the design of artificial structures on railways, such as bridges and traffic tunnels [3-7]. A full-scale in-situ experiment is the most revealing and reliable way of doing this [8], but such studies require a rather high investment.

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Laboratory stability tests provide the most complete information about the behavior of cohesive, rocky or artificially fixed soils under load [9, 10]. However, no methodology for pre-compaction of dispersed soil samples prior to testing has been developed for stabilisation tests [11-13], with the exception of tests on frozen dispersed soils [14]. Stabilometric tests on dispersed soils can therefore only be carried out in the bulk state and therefore the question of directly determining the physical and mechanical properties of building materials at their maximum density remains open.

Designed and validated by the authors of the article is a method of direct testing of compacted specimens in a single-plane shear apparatus to determine the strength characteristics - the angle of internal friction φ and adhesion c.

Stabilometric testing of dispersed soils with indirect determination of the deformation modulus of compacted soil has also been proposed by the authors in order to preliminarily assess the suitability of this soil as a building material.

2 Shear tests of dispersed soils

The department's research laboratory has been testing quarry sands from Kaliningrad (2015) and the Leningrad region (2016, 2017, 2018, 2020) as soils for embankments in recent years.

Any embankment is an artificially created foundation in accordance with domestic regulations. By compacting the packed sand layer by layer, the embankment soil acquires new physical and mechanical properties different from those of the naturally occurring quarry soil.

The Ele International, UK digital single-plane shear apparatus (Fig. 1) is well-proven for determining the strength properties of soils and can perform compression and shear tests on sandy and clayey soils.

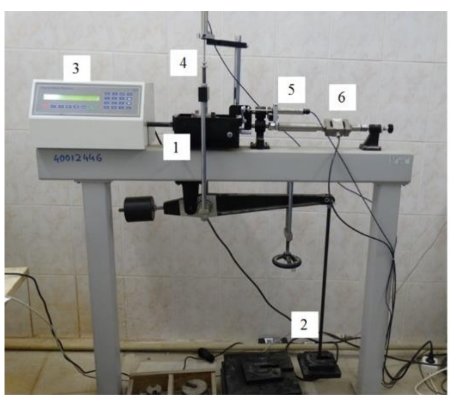

Fig. 1. Digital one-plane shift device: 1 - sliding carriage, 2 - lever loader, 3 - drive carriage, 4 - vertical displacement sensor, 5 - horizontal sensor, 6 - s-shaped dynamometer.

Soil sample preparation for testing shall ensure that its original structure and moisture content are almost completely preserved. Hence it is possible to either cut out a soil sample with a ring for in situ sampling or to bring a soil monolith to the laboratory and then cut it out for strength testing. For sandy (loose) soils such a requirement is almost impossible. The only exceptions are dusty and fine sands with dusty-clay particles sufficient for some preservation of the sample shape, but their use as artificial bases is inexpedient [15]. For medium to coarse sands, in turn, there are three possible methods of shear testing:

- testing of bulk sand (as disturbed soil);
- cutting out a sand sample after performing a standard compaction (figure 2, a);

– compacting the sand directly in the shear carriage with a rammer (figure 2, b).

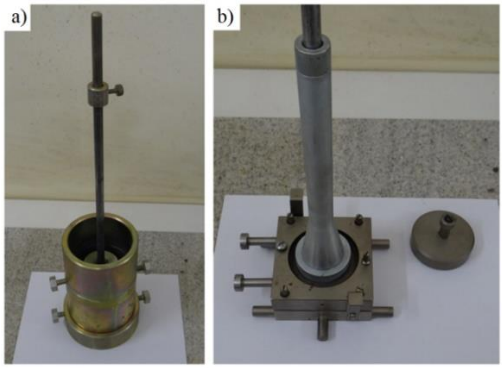

Fig. 2. Compaction of sand before shear tests: a - in a standard compaction device, b - tamping in a shear carriage.

Figure 3 shows diagrams for determining the strength characteristics of medium sand using all three methods. Reference data can serve as a criterion for the validity of the derived characteristics (E. A. Sorochan, Yu. Г. Trofimenkov et al., 1985), obtained from the results of field tests, giving us the expected angle of internal friction in the range of 38°.

When testing bulk sand, as can be seen from the diagrams, the vertical pressure on the shear apparatus does not ensure the formation of a dense artificial soil skeleton, and the angle of internal friction is very small.

All conditions corresponding to perfect compaction of sand in an embankment are met in the standard compaction device, yet when a sample is cut from the compacted sand mass it is irreversibly destroyed.

The most consistent result with the tabulated values is achieved when the sand is compacted directly in the shear carriage. The direct requirements of domestic standards are violated: the sample is not taken in natural compaction from a mass or monolith, instead an artificially compacted soil is created in the shear carriage to simulate the performance of the embankment body.

According to the results of the tests, we can conclude that this approach is applicable, despite some deviation from the standard methodology.

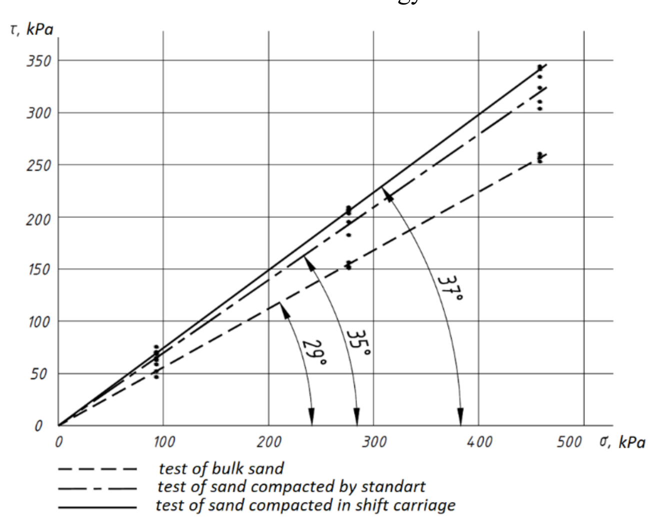

Fig. 3. Shear test results of sands.

3 Stabilometric tests of dispersed soils

The methodology proposed is based on the preliminary construction of a diagram of the relationship between strain modulus and porosity coefficient of a disperse soil using the known table values, being determined for soils of natural layering. Such a diagram should be extended to values corresponding to the porosity coefficient of bulk and artificially compacted soils.

Further actions are reflected in the flowchart shown in Figure 4. A standard disperse soil compaction is carried out in the first step to determine the porosity coefficient at the maximum density of the soil. Next, the density and moisture content of the soil in the bulk state and the porosity coefficient corresponding to this state are determined. Stabilometric tests are then performed on the soil at bulk density, after which the obtained value of the strain modulus is "superimposed" on the diagram. When correlated with the diagram, the strain modulus value of the compacted soil is also taken from the diagram. Failing this, the results of the test are rejected (if the value differs from the diagram by a smaller amount) or the value from the diagram is accepted without overestimation.

The diagram can also be subsequently adjusted based on the results of field tests.

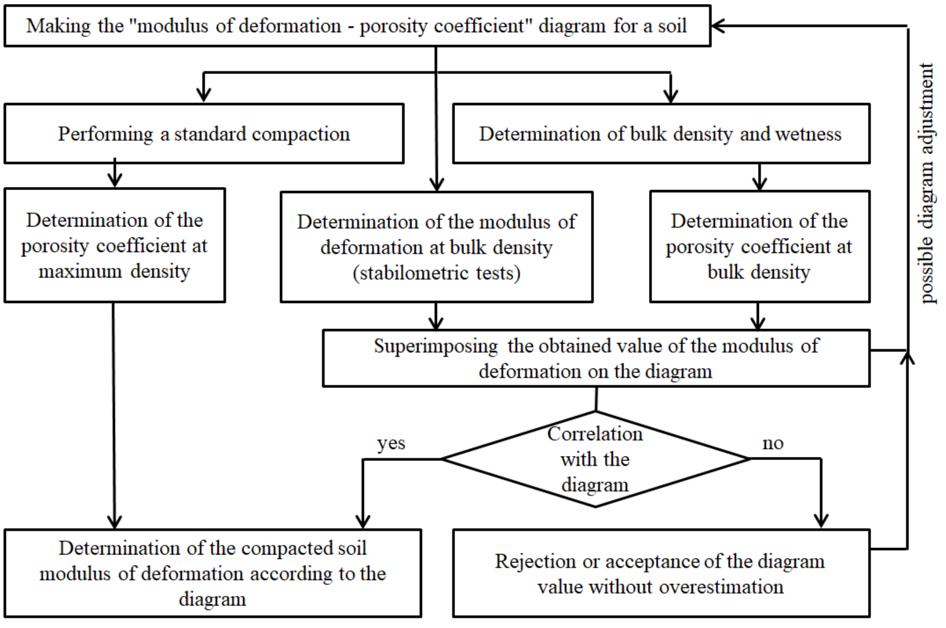

Fig. 4. Schematic of the methodology for stabilometric testing of dispersed soils with indirect determination of the deformation modulus of compacted soil.

The proposed methodology was tested on gravel-sand and sandy-clay deposits of the Russian Far North.

According to (E. A. Sorochan, Yu. Г. Trofimenkov et al., 1985) the main factor influencing the strain modulus, in addition to the type of soil, is the value of the porosity coefficient. Depending on the type of soils and, accordingly, the nature of the pore extent, the porosity coefficient may vary quite widely: from values close to zero to 12 and higher (organogenic soils).

The tabulated values of deformation modulus for naturally folded sands (both for gravelly and dusty sands) are determined at porosity coefficient e = 0,45...0,75; for plastic loams of natural folding - at e = 0,65...1,05 (table 1).

Building materials in bulk form are loose soils, the porosity coefficient in them can reach values of 2.0 or more. Simultaneously, artificial compaction, accompanied by abrasion of particles against each other and a sharp decrease in pore volume, can reduce the porosity coefficient to a value of 0.30...0.35.

Table 1. Reference values of the deformation modulus (MPa) of dispersed soils.

Soil type	The porosity coefficient *e*, e. unit.							
	0.35	**0.45**	**0.55**	**0.65**	**0.75**	**0.85**	**0.95**	**1.05**
Gravelly sand	–	50	40	30	20	–	–	–
Sand fines	–	39	28	18	12	–	–	–
Plastic loam	–	–	–	17	12	8	6	5

Therefore, the known tabular values of strain modulus for three types of soils (gravelly and dusty sands and plastic loams) were applied to the coordinate plane "strain modulus E - Porosity coefficient e" , after which the trend lines in areas of low and high porosity were determined using Microsoft Office Excel. The following diagram of the dependencies of the strain modulus on the porosity coefficient was obtained for gravelly sands, dusty sands and for flowing loams (fig. 5).

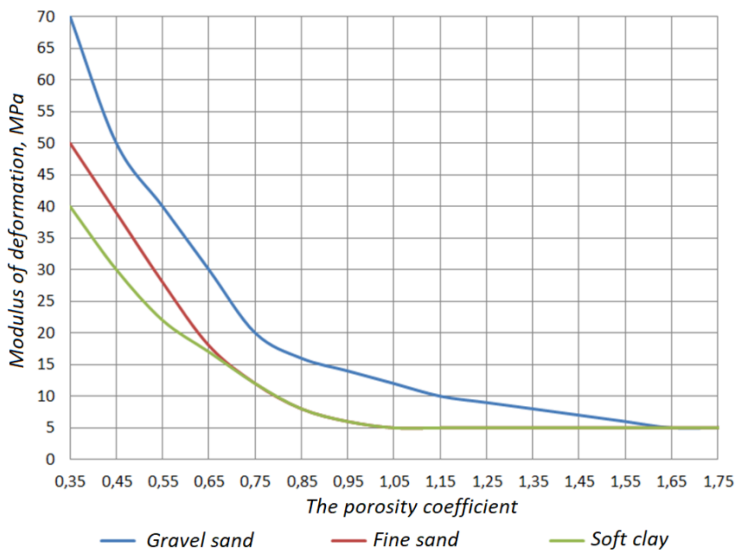

Fig. 5. Diagram of strain modulus dependencies on porosity coefficient for gravelly sands, dusty sands and for flowing loams.

The following stage of the research involved stylometric testing of samples of each type of soil at its bulk density.

The laboratory determination of strain modulus was carried out with an ELE-International Tritest 50 digital triaxial compression device (Figure 6) using the standard triaxial compression scheme at an all-round pressure of 0.2 MPa. For dispersed soils in their bulk state, testing is accompanied by inaccuracies in the height and diameter of the soil sample once it is in the stabilometer, which in turn affects the determination of the value of the relative strain and the strain modulus itself. Nevertheless, this error is estimated at 5...8 %, which is not critical in laboratory tests of soils.

At the same time, the maximum density ρ at optimum moisture w and the corresponding value of the porosity coefficient e were determined for each sample for further comparative analysis.

Fig. 6. Sample placed in the stabilometer test chamber: 1 - sample in a sealed chamber filled with water; 2 - S-shaped dynamometer; 3 - displacement sensor; 4 - water pressure sensor in a sealed chamber; 5 - retractable piston.

Seven types of soils were tested in total. Three stability tests were performed for each type. The average values of the strain moduli are plotted in the diagram in Figure 7. The same diagram shows the accepted values for soils in a compacted state. Analyzing the obtained values, we can conclude about the high convergence of most of the samples with the diagram. Two specimens (gravelly sand), however, showed a significant overestimation of the strain modulus compared to the diagram, and one specimen was rejected (clay material).

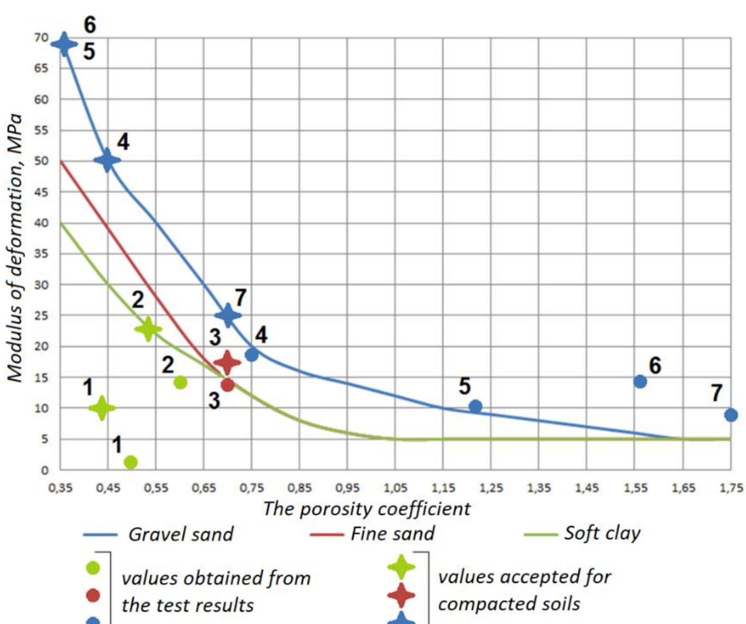

Fig. 7. Test results superimposed on the diagram of strain modulus vs. porosity coefficient.

4 Conclusions

1. Shear testing of dispersed soils is proposed, whereby the shear carriage simulates the conditions of the soil in the embankment body. The method has been tested in shear testing of quarry sands.
2. A methodology for stabilometric testing of dispersed soils with indirect determination of the deformation modulus of compacted soil is proposed. This technique can be used for a preliminary assessment of the suitability of soils as building materials. The methodology was tested during stabilometric tests of gravel-sand and sandy-clay soils.
3. Further adjustment of our strain modulus vs. porosity coefficient diagram based on the results of both laboratory and in-situ tests is deemed relevant.

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