Development of Soil Classification by Material Index (I_D)

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ABSTRACT: This paper reviews a practice of using the flat dilatometer (DMT) in the territory of the Russian Federation. Some issues related to use of the method and application of the results in compliance with the Russian standards are described. A particular emphasis is given to the determination of the soil type according to the DMT data. A comparison with laboratory test results is carried out and the newly adapted universal soil classification by soil index (I_D) can be proposed.

1 INTRODUCTION

In Russia, as well as in many other countries, while performing geotechnical studies to determine soil strength and deformation properties, preference is given to the field soil investigation methods. One of the basic investigation methods used in Russia is the geotechnical borehole drilling, which allows a soil massif to be described layer by layer, a soil type to be directly identified, samples to be taken for subsequent laboratory tests and determination of soil physical and mechanical characteristics for foundation designing. Field methods such as cone penetration tests and flat dilatometer tests are becoming more and more popular as they are timesaving, more informative and more efficient as a consequence but cannot allow the soil type to be directly determined as the investigations are performed in-situ without soil recovery to the surface. Therefore, the selection of formulas used to determine the most informative characteristics and divide the soil massif into geotechnical units depends on the exact soil type. This results in a need of developing a proper and universal soil classification based on the field test data.

The paper examines obtained results of DMT and laboratory investigations; the adapted soil classification using the material index proposed on the basis of the Russian classifications of soils.

2 RELEVANCE OF STUDIES

Currently, the DMT are not widely used in the RF (by contrast with the cone penetration tests). This can often be attributed to a common engineering practice accepted in our country to use "comfortable" data of laboratory investigations and in-situ plate load tests. Additionally, according to the RF legislation, the field method results can be used in the engineering provided if the following conditions are satisfied:

1. The test method shall be enlisted into relevant National Codes and described in the national standards (GOST).
2. The equipment used for tests shall be recorded in the National Register of Measuring Instruments.

The Russian flat dilatometer test method is stated in GOST 20276-2012, Attachment B. The procedure described in the standard generally coincides with the Marchetti flat dilatometer test procedure but there are a number of distinctions: a need of predrilling; use of rigid disk for load application that runs towards the soil in testing; non-availability of pore pressure measurement; a necessity of waiting for deformation stabilization.

On this basis, the Marchetti flat dilatometer application in Russia is a bit hampered because of absent regulatory documents that specify the test procedure, while the international regulatory documents (Eurocode, ASTM etc.) are not widely used in Russia so far as the geotechnical study results within the design documentation shall be subject to state or non-state expert review (which allows the geotechnical surveys to be performed in the frames of the RF standards only).

GEOINGSERVICE often cooperates with western designers (not uncommon performing surveys according to two standards in parallel because of non-availability of "universal" methods that can be appropriate for both regulatory documents) and often faces an issue of a required “adaptation” of the same field data results in Russian and foreign manner.

In this day and age, in order to allow flat dilatometer use as a universal method GEOINGSERVICE has launched a process of the test procedure introduction in the Russian regulatory documents (GOST, SP) and the test equipment – in the National Register of Measuring Instruments (since 2013, the company is practically the only owner of this equipment in Russia).

In spite of the differences in the regulatory documents as well as in geological conditions of survey areas throughout the world, the DMT can be used for determination of the soil types in various regions but with a particular uncertainty. To increase quality of obtained results, the regional correlation relationships, classifications and calculation formulas shall be developed.

Similar problems can be observed in using the cone penetration test. Regardless of availability of the recognized and widely used soil classification (Robertson&Campanella, 1983), there is no definite dependence between CPT initial data (q_c and f_s) and tested soil particle size. Moreover, any popular classifications based on initial data of the both test methods often include no structuring units – for instance, structuring of sand soils by grain size.

Besides, there are some discrepancies between classification systems in different countries. For instance, in the most widely used international soil classification (ASTM D 2487-11) the soils are divided into three large groups: clay, silt and sand. While as the Russian classification (GOST 25100-2011) recognizes four such groups: fat clay, lean clay, silty clay and sand. Surely, the boundaries among these groups are different both by particle size distribution and material index I_D.

GEOINGSERVICE has come to a conclusion that it is necessary to develop a classification that relates the material index not only with the soil type but with a universal parameter, e. g. percentage of various size particles in a tested soil. The availability of such classification could help users throughout the world to use test results regardless of the classification and/or normative base accepted in a certain country.

3 TEST AREAS AND METHODS

The DMT tests have been performed in various (geographical and geological) regions of the Russian Federation: Moscow, St. Petersburg, Nizhny Novgorod, Tobolsk, Perm etc. A total of over 50 test locations were performed with a total test depth of over 1000 m. (Fig. 1).

In order to solve the assigned tasks the flat dilatometer test results (TC 16) as well as the lab tests of clay and sand particle size distribution (hydrometer and screen tests respectively) (GOST 12536-79) and plasticity index of clay soils (GOST 5180-84) were used.

The geology of the test areas can be characterized by distribution of virtually all variations of soils – from heavy clays to gravelly sands (I_D of 0.02 to 5.81) in the upper section (to a depth of 40 meters).

In total, the analysis included the results of 4000

Fig. 1. Flat dilatometer tests performed in Russia: 1) Moscow region; 2) Penza; 3) Perm; 4) Tobolsk; 5) St. Petersburg.

DMT tests (approximately 900 m), 150 plasticity index tests and 140 particle size distribution tests.

It should be stated that the soils with coarse particle (d>2 mm) content of less than 10 % were used in the analysis. This is caused by minor occurrence and thickness of gravel and more coarse soils in the test areas to collect data for the analysis as well as a high probability of dilatometer membrane damage while penetrating and testing such soils.

4 PARAMETER RELATIONSHIPS

4.1 *Material index (I_D) and particle content of various size*

The soil particle size distribution results were analysed and represented as relationship diagrams of soil particle content of a specific size range versus the material index (Fig. 2-3). In the diagrams below, each point represents parameter values obtained during the soil tests at the same depth. The distance between the DMT location and borehole was not longer than 3 to 5 m.

The correlation of the material index and particle size distribution parameters is distributed by fractions:

1. The relationship of the material index versus content of clay fraction in soil – particle size of less than 0.002 mm (Fig. 2a).
2. The relationship of the material index versus content of silt fraction in soil – particle size of 0.002 mm to 0.05 mm (Fig. 2b);
3. The relationship of the material index versus content of sand fraction in soil – particle size of 0.05 mm to 2 mm (Fig. 3).

The analysis of the diagram in Fig. 2a shows that the relationship of I_D versus content of clay particles in the soil is exponential with a drastic fall of the material index as the clay particle content increases from 0 to 10 % followed by subsequent smoothing of the curve tending to its asymptote (zero line of clay particle content) with a further increase in its content.

The diagram 2b shows no clear correlation between the parameters under consideration, however, you can see that for clay soils (I_D < 1.5) The material index increases with an increase in silt particle content as for sand soils the inverse relationship can be observed.

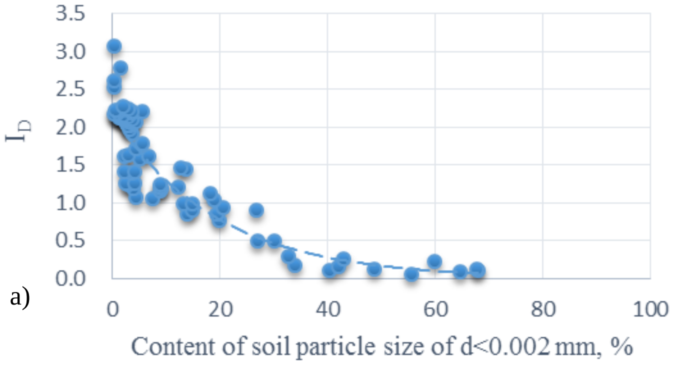
To perform a more comprehensive analysis of the effect of sand particle content (d of 0.5 mm to 2 mm) on the material index the three diagrams were plotted to show the relationship of I_D versus content of the following size soil particles: 1) d>0.05 mm (Fig. 3a); 2) d>0.1 mm (Fig. 3b); 3) d>0.25 mm (Fig. 3c).

The diagrams in Fig. 3a and 3b shows that the relationship of the material index versus the content of soil particles of a respective size is logarithmic. The fact that several points are beyond the common pattern can be explained by influence of greater sized particles (e.g. scattering of the points I_D>2.5 in Fig. 3b can be explained by availability of another correlation represented in Fig. 3c).

We can conclude from the abovementioned that the material index depends on the content of various soil particles sizes and these relationships can be quite accurately described by the equation or diagram curve and thus, these correlation results can be used for development of the soil classification.

4.2 *Material index (I_D) and plasticity index (I_P)*

a)



b)

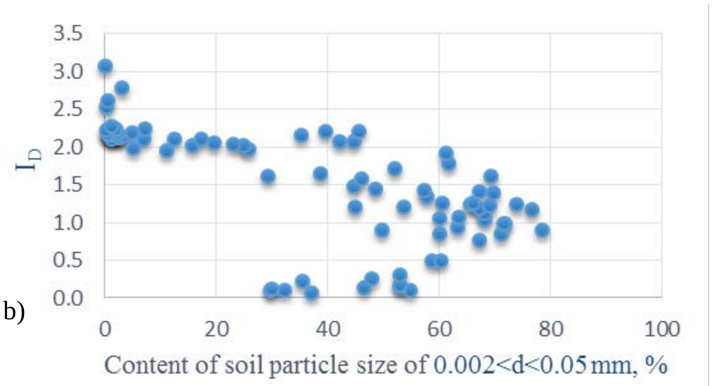


Fig. 2. The relationship of the material index (I_D) versus content of soil particle size a) d>0.002 mm; b) 0.002<d<0.05 mm.

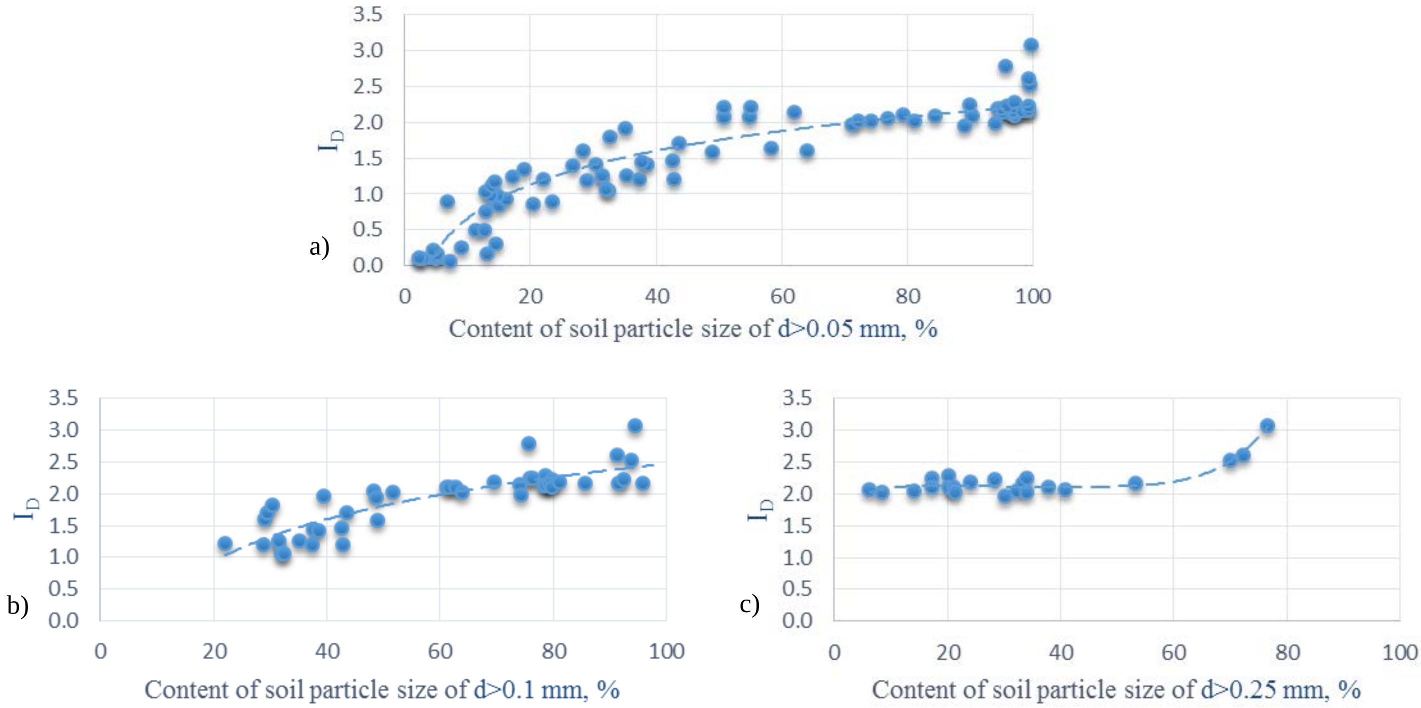


Fig. 3. The relationship of the material index (I_D) versus content of soil particle size a) d>0.05 mm; b) d>0.1 mm, c) d>0.25 mm.

The plasticity index determination results for clay soils were also correlated with the material index (Fig. 4). This correlation is exponential as in the correlation case of material index versus clay particle content, however, with a more gradual curve slope in the diagram.

The presented data analysis shows that the correlation between the parameters really exists and it can be described by the equation, however, it should be realized that each value of the material index can be corresponded to a range of both plasticity index and soil particle size distribution parameters values. Meaning that several tests shall be performed in the same geological element (at least 10 tests according to RF standards) to reduce soil characteristics determination error.

The determination factor of all the relationships shown in Fig. 2-4 is at least 0.85, which confirms a high correlation level between the parameters under study.

5 SOIL CLASSIFICATION

The adapted soil classification by the material index can be proposed on the basis of the identified correlation relationships (Table 1).

The classification structure, soil descriptions and ranges of used parameters are based on clay soil classifications by plasticity index and sand soils by particle size distribution according to GOST 25100-2011 as well as Okhotin's classification of soils by particle size distribution (Okhotin, 1933). These classifications are used in the paper as they are the most frequently used in the Russian Federation.

It is worthy of noting that when performing

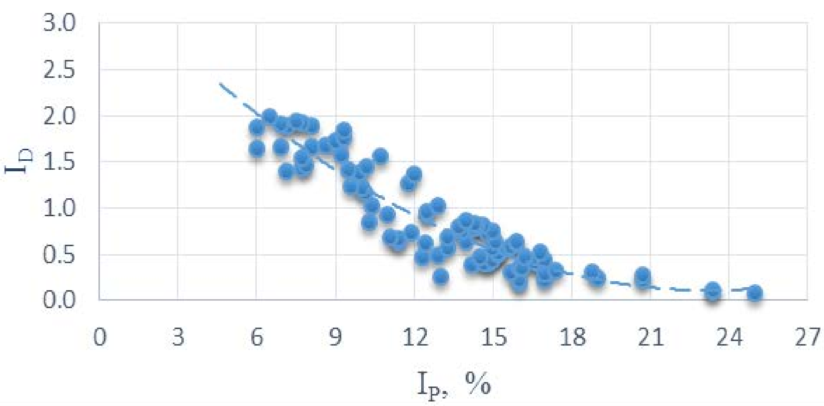


Fig. 4. The relationship of the material index (I_D) versus plasticity index (I_P).

Table. 1. Soil Classification by Material Index (I_D).

New Classification									DMT Classification (Marchetti, 1980)	
Soil description	Content of soil particle size mm, %						Plasticity Index I_P, %	Material Index I_D	Material Index I_D	Soil description
	clayey, d<0.002	silty, 0.002<d<0.005	sandy			coarse, d>2				
			0.05<d<2	0.1<d<2	0.25<d<2					
Fat clay heavy	>60	-	-	-	-		>27	<0.09		
Fat clay silty	30-60	-	<40	-	-		17-27	0.09-0.37	0.1-0.6	Clay
Fat clay sandy	30-60	-	≥40	-	-		17-27	0.37-0.43		
Lean clay heavy silty	17.5-30	-	<40	-	-		12-17	0.43-0.74		
Lean clay heavy sandy	17.5-30	-	≥40	-	-		12-17	0.74-0.84		
Lean clay light silty	10-17.5	-	<40	-	-	<10	7-12	0.84-1.46	0.6-1.8	Silt
Lean clay light sandy	10-17.5	-	≥40	-	-		7-12	1.46-1.64		
Silty clay	6-10	-	<50	-	-		1-7	1.64-1.88**		
Silty clay sandy	3-6	-	≥50	-	-		1-7	1.88-2.00		
Fine sand silty	<3	less than sandy	-	<75	-		-	2.00-2.2	1.8-(10)	Sand
Fine sand	<3	less than sandy	-	≥75	-		-	2.2-2.5		
Medium sand	<3	less than sandy	-	-	>50		-	>2.5*		

"-" - value is not regulated;
"*" - the upper limit is not defined;
"**" - the lower limit of the range based on the correlation with plasticity index only.

individual correlations of the material index versus the plasticity index and particle size distribution parameters, similar ranges of I_D values are obtained for similar taxonomic units assigned in two various classifications. It is another emphasis on convenient and reliable use of I_D as a criterion of classification.

Thus, the joint analysis of several parameters allows creating the correlations that relate the material index to the content of various soil particles developing the universal classification that matches these parameters with the soil types established in the territory of the Russian Federation and former CIS (Commonwealth of Independent States), i.e. in 1/6 part of the land.

6 CONCLUSIONS

1. The obtained result analysis shows that there are correlations between the material index (I_D) and the content of various soil particle sizes as well as the plasticity index (I_P). On the basis of these correlations, the soil classification by the material index was developed according to the soil types established in the territory of the Russian Federation.
2. The developed classification outlook and structure are preliminary and shall be extended and supplemented. The paper authors in the name of GEOINGSERVICE LLC offer collaboration to colleagues from different countries to create a common database with the subsequent development common database with the subsequent development of the universal soil classification. The development of such classification could significantly simplify operations of geologists throughout the world, in particular: the soil type could be determined more exactly, the soil body could be divided into elements, the calculation formulas could be correctly selected for resulting parameters etc. Following further improvement of the soil classification, the flat dilatometer tests could become a prevailing field test method among the test methods without soil removal on the surface.
3. The development of the universal soil classification by material index is a first step to creation of regional correlations and calculation formulas for other geotechnical parameters, e.g. deformation modulus, which could upgrade quality of results and increase appeal for this field test method in individual regions as well as in the whole world.

7 REFERENCE

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