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VARIABILITY OF BEARING RESISTANCE PROPERTIES OF SOILS

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Abstract: *The Institute of Theoretical and Applied Mechanics gathers long time (from 1997) identification data and shear resistance data of soils into a database. The database make it possible to register up to 145 data on any sample (39 identification data, 5 weight property data and 101 data of shearing resistance). The database has been completed from 1997 every year and contemporarily it covers data of 258 samples, hereof 5 gravel, 71 sandy and 182 fine grained ones. The Paper presents results of statistical evaluation of the last contemporary state of the database of year 2010. Implications for soil mechanics are mentioned.*

Keywords: ***Soil properties, shear strength, unit weight, identification data, statistical analysis.***

1. Introduction

Behaviour of soil and granular materials differs from other structural materials (e.g. concrete, steel, masonry, timber). In opposite to other structural materials the soil and granular masses are constructed from innumerous quantity of natural or artificial grains. Due to this fact, a basic attribute of soils is their variability and of course, also variability of their physical properties. Moreover, matter of all granular materials is diphasic or three-phasic (grain, water, air) and their behaviour is complex and non-linear.

It is logically resulting from upper mentioned facts that knowledge of both materials and their location is not perfect but, on the contrary often very low. The strong material variability occurs not only between different layers and their location but also usually due to the variability characterizes material into a layer. This fact is well-known but it causes fundamental difficulties both for design theories and practice. The greatest difficulty appears for the *geotechnical* Limit State Design (LSD) where an application of derived *design **material*** properties (instead most probable properties - probably B. Hansen 1953) has led due to non-linearity of geotechnical tasks to a fatal theoretical error.

Nevertheless, the soil and rock variability is a constitutive characteristics of geotechnical materials and it is important to know utmost on it. This knowledge is very important and useful for practice design but also necessary for a regular and solid calibration of both the LSD theory and of course, designs according to EC 7-1. The most important input data for the Ultimate Limit State Design (ULSD) are data of shear strength and unit weight. The upper mentioned reasons led to the establishment of a database of physical properties of soils in solid and reliable laboratories tested and concentrating on shear strength and unit weight.

2. Database

The database, according to its purposes, is specialized in demands of ULSD, shear strength and unit weight data (not deformation data). The shear strength database system is compounded from an identification block (39 data fields) and a block of physical properties (98 data fields). The database is divided according to soils up three parts: fine-grained and sandy soils and gravels regarding to the Czech standard ČSN 73 1001 "Subsoil under shallow foundations". The standard distinguishes five gravel groups (G), five sandy groups (S) and eight fine-grained groups (F). Denotation of soil kinds keeps the Czech standard ČSN 73 1001 and international usances as they follow:

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Fine grained soils:

F1 = MG (not applied),	F2 = CG (1 sample),
F3 = MS (32 samples),	F4 = CS (35 samples),
F5 = ML-MI (21 samples),	F6=CL-CI (50 samples),
F7 = MH-MV-ME (10 samples),	F8 = CH-CV-CE (15 samples).

Sandy soils:

S1 = SW (not applied),	S2 = SP (17 samples),
S3 = S-F (13 samples),	S4 = SM (29 samples),
S5 = SC (11 samples).	

Gravel soils:

G1 = GW (not applied),	G2 = GP (3 samples),
G3 = G-F (1 sample)	G4 = GM (not applied),
G5 = GC (1 sample).	

The database to date has data of 164 fine grained samples of groups F2 – F8, 70 sandy samples of groups S2 – S5 and 5 gravel samples of groups G2 – G3, .altogether data of 239 samples of Bohemian soils.

2.1. Identification data

The identification part involves all usual constitutive data about samples, i.e. soil description, year of performance of the tests, sample place in the soil mass, underground water level, sample location, testing person, stratigraphy and all basic characteristics of the sample soil: granularity, water volume, density.

Identification data are chosen so that it would be possible to make an exact comparison of data samples with other soils; a number of fields is of 39.

2.2. Weight properties

Data of volume weigh belong to fundamental physical properties which can be measured relatively easy and accurately. These data are placed in the database in 5 fields: natural unit weight, maximal and minimal ones, dry weight, material density.

From point of view of the ULS design the most applied property of this section is unit weight but others values can be useful for another tasks and for practice.

2.3. Shearing resistance properties

Values defining shear resistance are in the second section of the physical property part. The database is specialised in shearing resistance in terms of effective stress and both in top and residual values. However, not all tests are performed according to ČSN 73 1030 (Tests of shear strength) also for residual shear strength because the last movements do not satisfy prescribed values. For these cases, the residual values are derived from the accordant tests of top shear strength.

The database presents resulting values of shearing resistance in terms of effective stress both top and residual in 101 fields, i.e. top values of shearing resistance angle ϕ_{ef} and cohesion c_{ef} and residual values of shearing resistance angle ϕ_r and residual cohesion c_r , but also detailed results of box shear tests. Total shear strength value can be registered if it is tested but it is not needed or preferred.

2.4. Similarity parameters

The database monitors also two similarity soil parameters of ultimate design which are calculated using unit weight and shear strength properties. These parameters are denoted *Hamilton´s* and *Janbu´s similarity heights* h_π and h_λ resp. of quantity [m]. The parameters are defined as follows:

$$h_\pi \ = \ c_{ef} / \gamma \qquad (1)$$

$$h_\lambda \ = \ c_{ef} /(\gamma * tan \ \phi_{ef}) \qquad (2)$$

Both parameters can be found together with vertical parameters of soil or rock structures (e.g. height, depth) in ultimate design and then those are denoted as *Hamilton´s* and *Janbu´s similarity coefficients:*

$$\pi = c_{ef} / (\gamma * h) \tag{3}$$

$$\lambda = c_{ef} /(\gamma * h * \tan \phi_{ef}) \tag{4}$$

where c_{ef} and ϕ_{ef} are values shearing resistance (shear strength), γ is unit weight and h is vertical parameter.

The first similarity parameter (Hamilton´s) according to equation (3) influences ultimate designs directly, the second one (Janbu´s) according to equation (4) influences ultimate designs indirectly inducing locations of critical shear surfaces.

3. Statistical analysis

The presented statistical analysis has been carried out on the base of altogether 258 samples. Total sizes of single sets of soils are obvious in the description of the database in the Chapter 2.

Tab. 1: Statistical parameters of sandy and fine grained soils according to the database 2010.

TABLE OF STATISTICAL QUANTITIES OF SOIL DATABASE										
Mark	Samples	Average values			Medium deviations			Variability coefficients		
	n	$\square_m$	f_m	c_m	$s_\square$	s_f	s_c	$v_\square$	v_f	v_c
-	1	kgm^3	°	kPa	kgm^3	°	kPa	1	1	1
SANDY SOILS										
S1	0	-	-	-	-	-	-	-	-	-
S2	17	1810	39.1	7.3	112.96	5.01	4.57	0.062	0.128	0.627
S3	13	1880	36.7	13.8	171.17	5.91	10.99	0.091	0.161	0.794
S4	29	1927	33.8	19.9	150.35	6.59	17.11	0.078	0.195	0.860
S5	11	2115	24.5	18.0	91.24	2.57	19.97	0.044	0.096	0.678
SS	70	1912	30.7	12.9	138.61	5.53	14.54	0.072	0.180	1.123
FINE GRAINED SOILS										
F1	0	-	-	-	-	-	-	-	-	-
F2	1	2197	29.9	27	-	-	-	-	-	-
F3	32	1955	27.64	33.89	99.583	4.029	20.00	0.0509	0.1458	0.590
F4	35	2003	23.95	44.89	133.65	3.831	28.74	0.0667	0.160	0.640
F5	21	1993	22.42	38.00	99.81	3.035	22.27	0.050	0.1354	0.586
F6	50	2021	22.36	41.70	92.94	3.107	20.47	0.046	0.139	0.491
F7	10	1982	19.54	74.60	137.14	2.95	53.93	0.069	0.1511	0.723
F8	11	1953	16.76	47.80	137.29	1.894	17.03	0.070	0.113	0.356
SF	160	1993	23.18	43.16	91.42	3.394	26.00	0.046	0.146	0.602

Denotation of statistical quantities in the table is presented and the others are: n – number of samples, γ – unit weight, ϕ_m – average value of shearing resistance angle, c_m – average value of cohesion, s_x – medium deviations of relevant quantities in subscripts denoted, v_x – variability coefficients of the relevant quantity x. The groups S2 and F8 comprehend also properties of fills of soils belonging in the groups (5 samples and 4 samples resp.).

The Tab. 1 is a result of statistical analysis and it makes it possible to compare differences between quantities the single soil groups and their variability. Statistical weight of the results is given by size of the statistical sample set but all analysed sets are statistically sufficient and reliable. Statistical average parameters of the categories accord to well-known values very well.

4. Conclusion

The database and its statistical analyses can be very useful both for geotechnical research and practice. It have to be mentioned that statistical parameters of single soil groups has been derived from the whole sample sets of a number sites and due this fact statistical parameters of other site can be distinct. However, they should lie into or near range of the group/category according to the database.

The derived similarity parameters of soils, i.e. Hamilton´s and Janbu´s similarity heights, can be used to calculations of Hamilton´s and Janbu´s similarity coefficients if some geotechnical tasks are analyzed. A similarity approach appears very useful and effective.

5. Presentation of the database

The database has been developed through a number of years deriving benefit from a number of grant projects of the Grant Agency of the Czech Academy of Sciences and the Grant Agency of the Czech Republic. The database will be available at Internet address of ITAM

www.itam.cas.cz/

on the path (lidé/koudelka). The presented database is composed of four files: "Report" (in Czech), "Gravels", "Sands" and "Fine grained soils" in format pdf.

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