Proceedings of the XVII ECSMGE-2019
Geotechnical Engineering foundation of the future
ISBN 978-9935-9436-1-3

doi: 10.32075/17ECSMGE-2019-0991

XVII European Conference
ECSMGE 2019
Reykjavik
on Soil Mechanics
and Geotechnical Engineering

Applicability of relations between results from field and laboratory tests on sands from tailing dams

Applicabilité des relations entre les résultats des essais sur le terrain et en laboratoire sur les sables de les barrages de residue

S. Velkovska
Granit AD, Skopje, R. Macedonia

J. Br. Papić
University "Ss.Cyril and Methodius", Faculty of Civil Engineering, Skopje, R. Macedonia

ABSTRACT: There are several tailing dams in R. Macedonia with tremendous heights which ask for regular monitoring and control. Practicing of field and laboratory tests is understood, but prefers mutual relation, in order to reduce costs and speed up the process. Many general data can be found in literature, although also some for particular materials or locations, while it is notable the absence of such co-relations for tailing sand. Having in mind the importance of these dams, as well as their environmental and human impact, the paper checks the applicability of the available correlations based on results from large number of field and laboratory tests performed on active tailing dam in R. Macedonia.

RÉSUMÉ: Il y a plusieurs barrages de résidus en Macédoine avec des hauteurs énormes qui demandent une surveillance et un contrôle réguliers. La pratique des tests sur le terrain et en laboratoire est comprise mais privilégie la relation mutuelle afin de réduire les coûts et d'accélérer le processus. De nombreuses données générales peuvent être trouvées dans la littérature, bien que certaines concernent également des matériaux ou des emplacements particuliers, alors que l'absence de telles relations dans le sable de les barrages de residue est remarquable. Conscient de l'importance de ces barrages, ainsi que de leur impact environnemental et humain, le document vérifie l'applicabilité des corrélations disponibles sur la base des résultats d'un grand nombre d'essais sur le terrain et en laboratoire effectués sur un barrage de résidus actif à R. Macédoine.

Keywords: Tailing dams; sand; field and laboratory tests; correlations

1 INTRODUCTION

Tailing dams are complex structures mainly used for direct discharges and collection of raw metal mineral material pulp. These facilities are built for the purpose of water capture, capture of reagents used for degradation of ore minerals and some of the ore residues that remain in the flotation processing of minerals. They should be treated with great seriousness because the experience has shown that the consequences of inadequate design and treatment can be catastrophic. As such, beside monitored, their material properties are regularly checked by conducting field and laboratory tests.

In this research various tests are being made on a particular case of tailings sand to prove the properties of the material and the possibility data obtained with site work investigation to be co-related with data obtained via laboratory

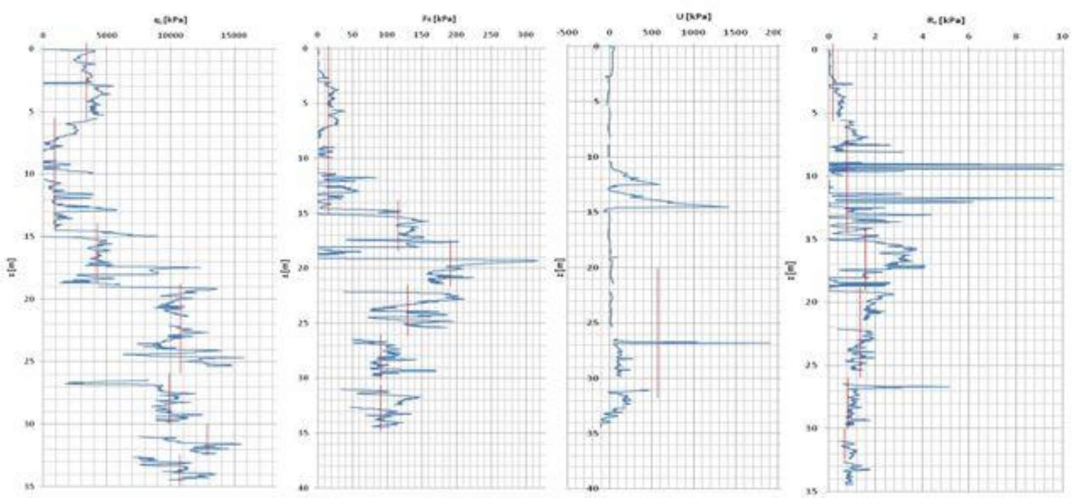

Figure 1. Cone penetration profile

tests on the same material. Namely, finding the correlation through which the site investigation results can be presented as laboratory results or through other field tests perspective has always been challenging. In this study, a digest on the work in this area has been made, through correlation of results from standard penetration test (SPT) and cone penetration test (CPT) and, on the other hand, from laboratory tests such as sieve, direct shear, triaxial and water permeability on properly taken samples.

2 METHODOLOGY OF INVESTIGATION

In order to complete the site works, a drilling of four boreholes with total length of 184 m was performed: three of them were 50 m deep and one was 34 m. SPT was performed all along their depth, while CPT was realized at particular depths. Moreover, there was also a separate point where only CPT was performed (Figure 1). During the SPT, samples were taken in a proper manner and transported to the geotechnical laboratory for testings, the main purpose of which was to classify them and assist in determining its physical and mechanical properties.

3 CO-RELATION AND COMPARISON OF THE SITE AND LABORATORY RESULTS

3.1 General

In order to complete the task, it was needed to ascertain the existing co-relations in form of equations, charts and tables in the literature, where results from field and laboratory tests would be overlaid and will show their effectiveness. Thus, the data usually gained in laboratory conditions could be obtained with minimal performance of field investigation, i.e. rational utilization of tests will apply. This would save time and money, while the results would be within the required accuracy.

So, with the data from SPT, information on mechanical properties of the material (density, angle of friction etc.) are achieved. The positive element in this test is that the obtained material is used for further laboratory investigations in order to get the same and other properties. Information on the mechanical properties are also got with CPT, but there are no samples.

Moreover, the review also included the recommendations offered in Eurocode 7-2.

3.2 Defining soil type

One of the main purposes of the CPT is to define the strata. Usually, the cone resistance (q_t) is greater in sands and smaller in clays, while the coefficient of friction ($R_f=f_s/q_t$) is low in sands and high in clays (Monnet, 2015). In interpreting the results from the CPT, Robertson is one of the most respected researchers, who has done numerous studies on this subject. Thus, for determining the type of material, he uses both normalised and non-normalised charts (Figure 2). The results from CPT in this tailing sand, applied on these charts, fit very well with results from laboratory grain size distribution tests and prove that we can obtain data from them with great accuracy.

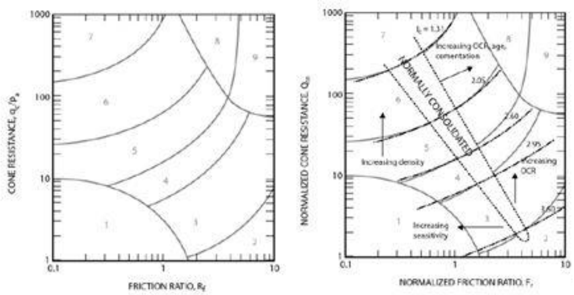

Figure 2. Non-normalized (left) and normalized (right) soil behaviour type chart (Robertson, 2010)

3.3 Correlations for determination of hydraulic conductivity (k)

An approximate estimate of soil hydraulic conductivity or water permeability, k, can be made from the soil type assessment using the normalized and non-normalized tables for prognozing the type of soil materials. Table 1 gives estimations based on the results from the CPT. These are approximate, but can serve as a guide to the range in which the permeability values are. So, in this case, the permeability obtained via laboratory tests was in range $k=2x10^{-5}\div1x10^{-3}$ m/s, which is almost the same as proposed in Table 1 for sands and approves its application at this type of materials.

3.4 Correlations for determining the angle of friction (φ)

The shear strength of non-cemented, coarse soils is most often expressed in relation to the peak of the secant angle of friction, φ'. Significant improvements have been made with developing theories of a model for CPT in sands.

Robertson and Campanella (1983) (Robertson and Cabal, 2014) suggest a correlation for estimating the peak friction angle for unbound, moderately compressive, mostly quartz sand based on the results of the calibration test. For sands with high compressibility (i.e. carbonate sands or sands with high content of mica), the method will tend to predict low angles of friction

$$\tan\varphi' = 1/2.68*[\log(q_c/\sigma_{vo}')+0.29] \qquad (1)$$

Kulhawy and Mayne (1990) (Robertson and Cabal, 2014) proposed an alternative relationship for clean, rounded, un-cemented quartz sands and evaluated the relationship using high quality data obtained from field tests:

$$\varphi' = 17.6+11\log(Qtn) \qquad (2)$$

Table 1 Estimated soil permeability (k) based on the CPT/SPT chart by Robertson (2010)

Type	Material description	*k* (m/s)	*Ic*	$[(q_c/P_a)]/N_{60}$
1	Fine grained	$3x10^{-10}\div3x10^{-8}$	/	2.0
2	Organic soils – clay	$1x10^{-10}\div1x10^{-8}$	$Ic > 3.60$	1.0
3	Clay	$1x10^{-10}\div1x10^{-9}$	$2.95 < Ic < 3.60$	1.5
4	Silt mixture	$3x10^{-9}\div1x10^{-7}$	$2.60 < Ic < 2.95$	2.0
5	Sand mixture	$1x10^{-7}\div1x10^{-5}$	$2.05 < Ic < 2.60$	3.0
6	Sand	$1x10^{-5}\div1x10^{-3}$	$1.31 < Ic < 2.05$	5.0
7	Dense sand to gravelly sand	$1x10^{-3}\div1$	$Ic < 1.31$	6.0

Table 2 Values for angle of friction obtained by correlations from the results of CPT and SPT

		Estimated angle of friction through correlations from CPT					Labora-tory	Estimated angle of friction - correlations from SPT		
Borehole	Depth	1	2	3	4	5		6	7	5
B-1	30.0 ÷ 32.35	24.52	31.80	28.56	28.0	31.95	**36.5**	25.9	28.8	34
	43.15 ÷ 45.5	29.77	35.66	34.13	30.0	37.22	**35.5**	27.2	29.4	34
	40.37 ÷ 42.04	30.79	36.43	35.23	37.0	38.26	**32.1**	28.4	29.9	34.5
B-3	33.0 ÷ 35.0	26.18	32.76	29.95	/	/	**33.4**	21.7	28.2	29
	42.0 ÷ 44.25	30.34	36.21	34.91	34.0	37.67	**36.2**	27.1	29.5	34
B-4	15.0 ÷ 18.53	28.14	32.07	28.95	22.0	29.63	**29.9**	24.7	28.2	29
	34.0 ÷ 37.0	28.17	35.27	33.57	/	/	**36.6**	25.7	29.9	33

1) Robertson and Campanella (1983) **2)** Kulhawy and Mayne (1990) **3)** Jefferies and Been (2006)
4) Nonveiller **5)** EC7-2 **6)** Kulhawy and Mayne / Schmertmann **7)** Wolf / Peck-Hanson-Thornburn

The results from this two, as well as several other representative methods and published experiences, are presented in Table 2. From them, the following conclusions can be extracted. Namely, it can be noticed that when it comes to correlating the results obtained from the CPT with laboratory results, the closest values in this case of tailing sand are obtained by the suggestion of Kulhawy and Mayne (1990), while in correlating the results from SPT, nearest values are obtained by following the recommendations given in Eurocode 7-2.

4 CORRELATIONS BETWEEN RESULTS FROM CPT AND SPT WITH RESULTS FROM OEDOMETER TESTS

Oedometer test is carried out in laboratory conditions, in an apparatus with bounded lateral displacements, in order to get its deformability properties. The material is being consolidated within 24 h, in several stages, up to loads corresponding to the ones of the overlaying sand on the depth where the sample has been taken from, so that this modulus of compressibility E_{oed} can be compared with the values obtained through co-relation with CPT and SPT. If not explicitly present, than these loads were used to estimate the E_{oed} from the oedometer test, following the dependence in the obtained diagrams. The estimated values for these loads are applied as benchmarks for comparison with the values that would be calculated according to certain existing expressions for correlating present in the literature.

In general, comparisons were made between laboratory measurements and corrected SPT data, using Bowles' recommendation (Naeini, Ziaie Moayed, Allahyari, 2014). From the given in Table 3, it can be noticed that this expression gives acceptable results.

In regards to the comparisons with CPT, they are made using De Beer's and Buisman's recommendation for sand, in which the average cone resistance is increased 50-200% to assess the laboratory E_{oed}. Unfortunately, due to the variation of the values and to the lack of data from certain measurements, no firm conclusion can be drawn as to which percentage is valid. However, 1.5 is certainly acceptable for the tested material and usually is on the safety side.

Table 3 Values for compressibility modulus obtained with oedometer tests and through correlations with CPT and SPT

Borehole	Depth [m]	q_c [MPa]	E_{oed} [MPa] obtained through CPT, $1.5 \div 3q_c$	E_{oed} [MPa] obtained through SPT, by Bowles 0,32N'+4,8	Comparable laboratory E_{oed} [MPa]
B-1	30			12.2	9.4
	30.0÷32.35	4.5	6.75÷13.5		>11
	33			11.0	>12
	36			12.9	>13
	39			14.3	16.9
	43.15÷45.5	11.1	16.65÷33.3		>18
	45			16.1	>18
	50			17.8	>18
B-2	40.37÷42.04	13.2	19.8÷39.6		>17
	44.5			15.7	>17
	50			14.0	>13
B-3	33.0÷35.0	5.4	8.1÷16.2		13.8
	36			9.7	13.8
	39			12.6	17.2
	42.0÷44.25	12.85	19.3÷38.6		>17
	48			12	>16
B-4	2.5			6.5	1.1
	5			6.4	3.5
	7.5			7	3.9
	10			8.4	8.3
	12.5			7.9	2.6
	15.0÷18.53	3.1	4.65÷9.3		8.5
	21			12.5	14.3
	24			12.5	10.22
	27			14	12
	30			12.8	14.7
	34.0÷37.0	11.8	17.7÷35.4		>15

5 CONCLUSIONS

The main purpose of this paper was to give review of the existing correlations between field, particularly SPT and CPT, and laboratory tests from the tailing sand point of view. Most of the tables and charts, and some of the formulas are fitting to be used in materials as in this case. Namely, some of them offer general data, while some give specific values. So, from this research it can be concluded that:

- charts and tables proposed by Robertson can be used for defining the type of material and its permeability from CPT;
- Kulhawy and Mayne's equation is recommended for obtaining angle of friction through CPT;
- EC7-2 proposal is valid for its derivation from the SPT;

- compressibility modulus from CPT can be obtained with certain positive reserve from De Beer's expression, while
- Bowles' equation seems fine for the same from SPT.

As it could be noticed, tailings dams and sands are specific engineering problem that is unusual, but serious, and therefore require special attention. In future, during next monitoring and control study on tailing dam of this type, it is suggested to take into consideration and re-examine the above given recommendations in order to confirm or improve their functionality: their application would surely be beneficial both for the investors, engineers and researchers.

6 ACKNOWLEDGEMENTS

This research was conducted as a part of a large project and for the purposes of master thesis, for which the laboratory tests were conducted at the Chair of Geotechnics at the Faculty of Civil Engineering in Skopje, R. Macedonia. The authors are grateful to the work of the personnel.

7 REFERENCES

Fauzi, J. et al. 2015. A new correlation between SPT and CPT for Various Soils, *World Academy of Science, Engineering and Technology International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering* **Vol.9, No.2**

Robertson, P.K., Cabal, K.L. 2014. *Guide to Cone Penetration Testing for Geotechnical Engineering*, 6th Edition

Robertson, P.K. 2010. Evaluation of Flow Liquefaction and Liquefied Strength Using the Cone Penetration Test, *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, June 2010

Eurocode 7 – Geotechnical Design – Part 2: Ground investigation and testing. 2007.

Das, B.M. 2007. *Fundamentals of Geotechnical Engineering*, 3rd Edition

Naeini, S.A., Ziaie Moayed, R., Allahyari, F. 2014. Subgrade Reaction Modulus (Ks) of Clayey Soils Based on Field Tests, *Journal of Engineering Geology,* **Vol.8, no.1**

Monnet, J. 2015. *In Situ Tests in Geotechnical Engineering*