Appendix to correlation between E_{oed} and q_c for silts

Appendice à la corrélation de E_{oed} et de q_c pour les sols poussièreux

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ABSTRACT
The field where geotechnics can offer help in increasing project speed realization and minimizing their expense is to find out the parameters needed for analysis through already known parameters and earlier based correlations and equations.
There have been developed many field and laboratory tests for determining soil properties. In the soil mechanics history there have also been recorded many attempts for defining correlations between the results from field investigations and parameters obtained from laboratory tests. Some of them are based on the results from cone penetration test CPT where, among the rest, there are suggestions for determination of oedometer modulus of compressibility E_{oed} from cone resistance q_c, but mostly for coarse grained soils. There are also suggestions for other types of soils, but there the correlation factors vary in pretty large domain. This paper gives opportunities for establishing correlation between the value of cone resistance q_c achieved in the cone penetration test in silts in absence of water, and the modulus of compressibility E_{oed} determined in oedometer test.
As it is usual in soil mechanics, these can be used for approximate determination, and to certify it for wider domain of granulometric content and conditions it is necessary to realize more investigations on several variations of fine grained soils.

RÉSUMÉ
La geotechnique peut offrir la main pour réduction du temps de travail et diminution de prix du project, en trouvant les mesures d'analyse à l'aide des mesures, des corrélations et des 'equations connues.
Beaucoup de champs et de tests du laboratoire sont développes pour déterminer les propriétés du soil. Au cours de l'histoire de la gèomécanique on est remarqué beaucoup d'essais pour définir les corrélations entre les résultats de l'investigation des champs et des mesures obtenues dans les tests du laboratoire. Quelqu'uns sont basés sur les résultats de la pénétration du cône test (CPT), où il y a des suggestions pour determiner l'oedomètre module de la compression E_{oed} à la résistance du cône q_c, mais la plupart d'eux sont pour les sols avec grand grains. Aussi, il y a des suggestions pour d'autres types du sol, mais là les facteurs de la correlation sont très variables. Ce papier donne l'occasion d'ètablir une correlation entre la valeur de la résistance du cône q_c, réalisér avec le test de la pénétration du cône (CPT) dans les sols poussiéereux en absence d'eau, et le module de la compression E_{oed}, determinée dans le oedomètre test conventionnel.
Comme d'habitude, en gèoméchanique, cela peut utiliser pour la détermination approximative, et pour certifier dans le domaine plus large, il est nécessaire à réaliser plusieurs investigations avec les variations des fin grain sols.

Keywords : correlation, field investigations, laboratory tests, CPT, cone resistance q_c, oedometer modulus of compressibility E_{oed}

1 INTRODUCTION

The implementation of Cone Penetration Test CPT is often recommended, beside for sands, as an appropriate in-situ test for fine grained soils. This test is very useful and economic because it enables decreasing the number of boreholes at the site. It consists, among the rest, of measuring the soil resistance to cone penetration which is dimensionally consistent to stresses as well as to the modulus of compressibility. Many years ago this was a starting point for analysis for inventing typical relations between the cone resistance q_c and modulus of compressibility E_{oed} achieved through oedometer test.

Since that there are no samples provided from the CPT for laboratory tests, when planning investigation works this test is combined with related methods of boring wherefrom samples can be obtained.

2 PAST EXPERIENCES

There are many empirical correlations which enable determination of parameters, usually obtained through laboratory tests, from in-situ results and thus the laboratory tests can be avoided. However, these correlations, as many other in soil mechanics, do not need to have universal meaning because they mostly depend upon local conditions.

The dimensional consistency of cone penetration resistance and modulus of compressibility is used for creating several empirical expressions for their direct connection. Some of them were used in the practice, but no matter of the form how they are expressed, for most of them it is characteristic that they are dedicated for coarse grained soils – sands.

In the Eurocode 7, part 2, there are expressions for determining modulus of compressibility E_{oed} from cone penetration resistance q_c for fine grained soils, but these expressions depend upon coefficient "α" variable in large domain.

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3 INVESTIGATIONS AND RECOMMENDATIONS FOR FINE GRAINED SOIL

For the need of a structure near city Skopje, Republic of Macedonia, a CPT was conducted. The diagramme and values of cone penetration resistance q_c from CPT can be seen at Figure 1.

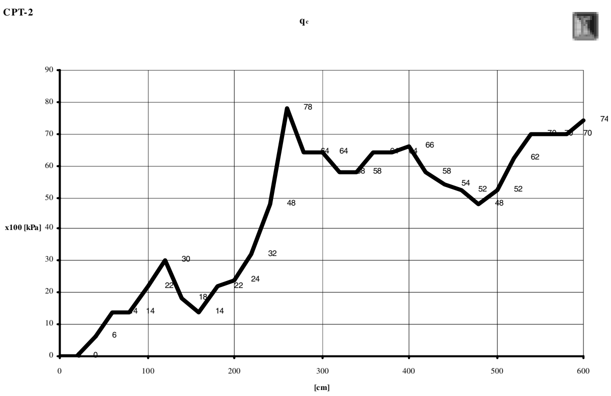

Figure 1. Diagramme of cone penetration resistance

Very near to this point where CPT was conducted, a trial pit was excavated in which there was no groundwater registered. This trial pit served for taking samples for laboratory tests: soil classification and determination of soil properties. Granulometric sieve test, consistency limits and oedometer tests were conducted in laboratory. According to the classification, there was sandy silt on depth of 4.00-5.00 m and lapor silt at 5.00-6.00 m. The granulometric content is shown at the following diagramme on Figure 2.

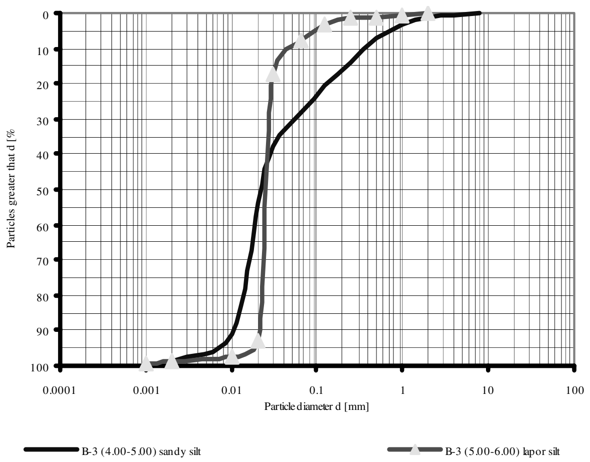

Figure 2. Granulometric content of silts

The dominant presence of fine particles suggested realization of Atterberg's test for determination of consistency limits, after which it was obvious that these materials had intermediate plasticity (MI-MI/CI).

Paralel to these classification tests, oedometer tests were conducted on both encountered silts. But, since that there was no ground water registered on the location during excavation of trial pit, it gave an idea for realization of these tests both on saturated and non-saturated samples. The results are enclosed below on Figure 3, where are diagrammes from oedometer tests for both sandy and lapor silt conducted in saturated condition, as well as for lapor silt realized in non-saturated condition.

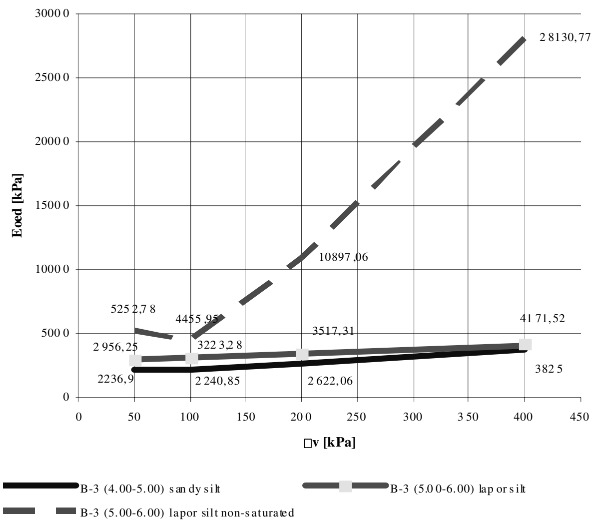

Figure 3. Modulus of compressibility for tested soils

The oedometer test for samples from both depths (4.00-5.00 m and 5.00-6.00 m) was conducted under conventionally used loads: 50, 100, 200 and 400 kPa. The achieved results from the oedometer test, as well as from the CPT for the depths wherefrom the samples were taken are presented in the Table 1, where are also their average values.

Table 1. Registered values of oedometer modulus of compressibility and cone resistance for both silts

Depth [m]	4.00 - 5.00		5.00 - 6.00		
Parameter	E_{oed}	q_c	E_{oed}	E_{oed} (non-saturated)	q_c
	2237	5800	2956	5252	6200
	2241	5400	3223	4455	7000
	2622	5200	3517	10897	7000
	3825	4800	4171	28130	7000
		5200			7400
Average	2731	5280	3467	12184	6920
E_{oed}/q_c=	0.517		0.501	1.76	

If we compare the average values of modulus of compressibility and the cone resistance for these depths, it is obviuos that there is certain similarity which can be simply expressed as

$$E_{oed}=0.5*q_c \tag{1}$$

which expression gives relation between the modulus of compressibiity obtained from oedometer test in water saturated conditions and cone resistance in situation without presence of water. But, as many other expressions in soil mechanics, it can be used for preliminary estimation of modulus of compressibility.

According to the laboratory measurings, the silts' bulk densities were 16.3–16.6 kN/m^3, so that the in-situ vertical stresses at average depths of 4.50 m and 5.50 m were about 75 kPa and 90 kPa, respectively. At those depths, the registered cone resistances were 5300 kPa and 7000 kPa, respectively. The results of the oedometer test were used for calculation of values of oedometer modulus for stresses equal to the in-situ vertical stresses, when the values are about 2240 kPa and 3200 kPa. Comparing these E_{oed} to q_c, it can be found out that for both cases

$$E_{oed} \approx 0.45 * q_c \quad (2)$$

what is very near the previous relation and kind of its confirmation.

Since that Republic of Macedonia is in process of involving Eurocode standards, it was interesting to make a simple check of Eurocode 7 recommendations, where are several for correlating cone penetration resistance q_c and oedometer modulus E_{oed} through parameter "α" for different types of soils. This correlation parameter depends upon q_c and its value is in domain 1-2 for silty soils where q_c>2 MPa. Respecting that there was no water registered in the field, another oedometer test was realized on lapor silt in the same conditions as the one encountered in the field i.e. in non-saturated conditions, which results are also shown in the Table 1, presented above. It can be seen that the rate E_{oed}/q_c for their average values for this case is about 1.7, or

$$E_{oed} = 1.75 * q_c \quad (3)$$

what is in the range recommended in Eurocode 7. Of course, for its confirmation there is need of many more investigations and work, although the time for starting implementation of Eurocodes is rapidly decreasing.

4 CONCLUSION

To enable fast and quality designing and building of any kind of civil engineering structure, it is necessary to realize adequate investigations and tests. The goal of geotechnical investigations is to achieve confidental informations for the soils in the site area and to define the soil's engineering properties, like strength parameters, deformability and other parameters of soil behaviour in natural conditions and in situation after construction of structure. There are many terrain investigations and laboratory tests developed for determining physical and mechanical soil properties. Some of the laboratory tests look after long time period for their realization, and even then the results can be influenced by the human factor. It is already known that the process of taking samples, their preparation and installing in the laboratory equipment is not always successfully done. There is also the natural condition disturbance factor. From that reason, there is a special concern in getting information from terrain investigations, straight or indirect, using relations for defining other parameters needed for calculations. Since that the properties can be defined in original form, the in-situ investigations are preferable as more adequate and relevant, but they are also complemented with laboratory tests of some properties. From the aspect of time and money consuming it seems attractive to avoid laboratory tests and to define the needed parameters based on some correlation with the field investigations.

The most wanted combination is to combine the field and laboratory tests. Since that the terrain ones are more relevant and that they picture better the real soil condition, but that they can't determine some parameters needed in calculations which are obtained in laboratory, it is necessary to find out correlations between them. The CPT is one of the most popular and conducted tests and therefore, by now, there are many correlations for results from CPT and oedometer test, cone resistance q_c and modulus of compressibility E_{oed} respectively, but mostly for coarse grained soils. This paper deals also with correlation between the same parameters, but for silts. From the results presented above, it can be concluded that the value of modulus of compressibility achieved for saturated sample of intermediate plasticity silt is about half from the cone resistance registered in conditions without any presence of groundwater. When comparing the result from oedometer test conducted on non-saturated sample, what correlates to the field conditions, the value of E_{oed} is about 1.75 times greater than q_c, what is in agreement with recommendations specified in Eurocode 7.

As all earlier presented empirical equations, it is recommended to use this one just for preliminary calculations. For increasing and confirming its confidence, it is suggested to realize larger number of combined terrain investigations and laboratory tests on more different types of fine grained soils at various conditions.

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