2

1221

XXV AIAS NATIONAL CONFERENCE
INTERNATIONAL CONFERENCE ON MATERIAL ENGINEERING
Gallipoli - Lecce, 4-7 September 1996

The validation of correlation laws for some properties of normally consolidated clays.

C. Cherubini, L. Cucchiararo, C.I. Giasi, F. Santoro

Istituto di Geologia Applicata e Geotecnica. Politecnico di Bari.

KEYWORDS: Clays, Correlation laws, Compression index, Angle of shearing resistance, Liquid limit, Overconsolidation ratio.

ABSTRACT

We can consider the soils as "materials" having a great variability of their properties. In practical geotechnics is usual to use the results of various tests to get, starting from easier to obtain properties, information of greater importance in the applications. It's usual to use, for the aim, empirical relations derived from statistical elaborations. Among the relations which are most in use, are pointed out the ones that links together the compression index with a basic property (e.g. liquid limit, natural water content, void index, etc.). A well known empirical relation which allows to obtain the overconsolidation ratio starting from the shearing resistance angle, the undrained cohesion and the effective vertical stress, shows a great range of variability. Are also pointed out some relations of quite good reliability which allows to evaluate the shearing resistance angle by means of the plasticity index.

At last these investigations, although based on a limited data sample taken from literature (and hence not really quantitatively exhaustive) gives quite interesting results both regarding the practical use of the already existing relations and in the theoretical study. In particular the verification of these laws by means of experimental data can allow the improvement of the reliability of these relations.

INTRODUCTION

With the term "soil" we identify materials with different grain sizes (from few μm to some cm of equivalent diameter) with a significant and variable porosity, different structures correlated to stress history (especially in the case of clays)

These aspects, with other important components involved, require several different kind of tests in laboratory and/or in situ in order to investigate the physico-mechanical behaviour of soil. So we have a redundancy of data, typical feature of geotechnique.

These reasons, and other reasons related to the need to have information about mechanical parameters (even if not very accurate) considering laboratory-test results about simple properties, have made correlation between simple properties and more complex properties very successful in geotechnics. These relationships are generally empirical but sometimes are supported by theoretical model. In particular, when we have an empirical correlation developed with statistical evaluation, the relation obtained is relevant for a particular kind of soil and, with many advantages, it could have some disadvantages.

THE "VALIDATION" OF SOME CORRELATION LAWS

In order to point out the strengths and weaknesses of the different approaches, we examined a considerable quantity of data (50 samples) concerning normally consolidated clays from different countries of the world. These data [4] can be the basis for useful theorising and research because are reliable as they are often mentioned and used in literature but they concern only a part of soil (NC clays) even showing a wide variability of the examined characteristics.

One of the most used correlation in geotechnics is the correlation between compression index C_c (which is representative of the variation of void index Vs applied vertical stress variation) and an index parameter (liquid limit W_L, natural water content W_N, void index e, etc.)

Since 1944 Skempton [12] found a correlation between compression index of remoulded clays and the liquid limit that is:

$$C_c = 0.007 \cdot (W_L - 7)$$

Terzaghi and Peck [13] modified the Skempton's equation in order to apply it to normally consolidated clays, obtaining

$$C_c = 0.009 \cdot (W_L - 10)$$

Many other researchers proposed correlation between C_c and the liquid limit, the void index and the natural water content, in a separate way.

In Tab. I are summarised some correlations, proposed during the years, that link C_c to W_L [3].

Equation	Applicability	Author	Year
A1 $C_c = 0.007 \cdot (W_L - 7)$	Remoulded clays	Skempton	1944
A2 $C_c = 0.0046 \cdot (W_L - 9)$	OC remoulded clays	Cozzolino	1961
A3 $C_c = 0.009 \cdot (W_L - 10)$	NC clays	Terzaghi-Peck	1967
A4 $C_c = 0.006 \cdot (W_L - 9)$	Clays with W_L<100%	Azzouz et al	1976
A5 $C_c = (W_L - 13)/109$	All clays	Mayne	1980
A6 $C_c = 0.007 \cdot (W_L - 5.3)$	NC clays	Ricceri	1971
A7 $C_c = 0.21 + 0.008 \cdot W_L$	Bangkok clays	Adikari	1977
A8 $C_c = 0.00604 \cdot W_L$	NC clays	Nagaraj	1986

Tab. I - Correlations between compression index C_c and liquid limit W_L

Fig. 1 graphically shows these correlations and reports measured data of the 50 samples we can use.

It's easy to observe some relevant aspects:

-the empirical laws described provide to point out the range in which C_c lies when W_L is varying;

-the different correlations are substantially converging with high values of W_L, while for values of W_L less then 50% tend to diverge and this divergence becomes appreciable for values of W_L less the 25%. This happening suggest to not apply these relations without particular attention;

-the different correlations show a wide range of variability. This concerns the fact that every correlation is obtained through statistical procedure on the basis of different data.

As we said before, not only relations between C_c and W_L exist. For example Nagaraj and Srinivasa Murthy [10], [11] linked the compression index to the void index at the liquid limit e_L

$$C_c = 0.231 \cdot e_L$$

We have to remind that there are some correlation that link C_c to several index properties; for example in Carrier's correlation [2] appear the natural water content W_N, the plastic limit W_P, the plasticity index PI and the activity A

$$C_c = 0.329 \cdot \left[0.027 \cdot (W_N - W_P) + 0.0133 \cdot PI \cdot (1.192 + A^{-1})\right]$$

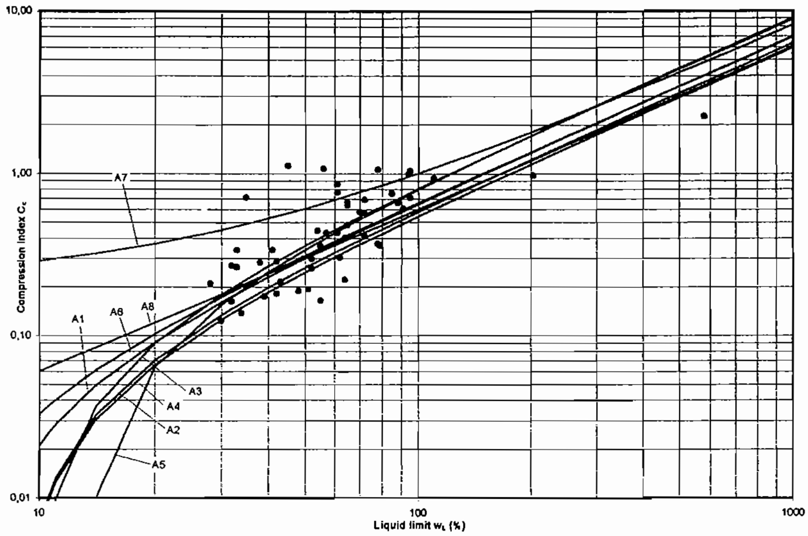

Fig. 1 - Graphic of the correlations of Tab. I with sample's measured values overlaid

Another interesting aspect concerning correlations between different properties of soils is represented by correlations between undrained cohesion, effective vertical stress, OCR and undrained shearing resistance angle.

It's well known [6] that the undrained cohesion c_u in normally consolidated soils linearly increases with the effective vertical stress. In particular the ratio c_u/σ'_{v0} for some italian NC clays varies between 0.15 and 0.40 [1]. In the case of overconsolidated clays this ratio is closely dependent on OCR (Over Consolidation Ratio). Recently Mayne [7] proposed the following formula

$$OCR = \left(\frac{\frac{c_u}{\sigma'_{v0}}}{0.75 \cdot \text{sen}\,\phi'} \right)^{1.43}$$

Although, generally, the degree of overconsolidation is calculated by tests results, in this case we will use Mayne's correlation in order to obtain the value of OCR backwards through the values of c_u/σ'_{v0} and of ϕ' that we have for the 50 samples already mentioned. The result of this applications are summarized in the histogram of Fig. 2. The mean value of OCR, obtained from data, is 0.969 and the standard deviation σ_{OCR} is 0.287. Then we can state that:

- with the mean value obtained, Mayne's correlation anables us to evaluate OCR with good precision;

- the dispersion is somewhat sensible (CV_{OCR}=28%), but, however, it is of the same quantity as the empirical estimation made in geotechnics with a quite good accuracy.

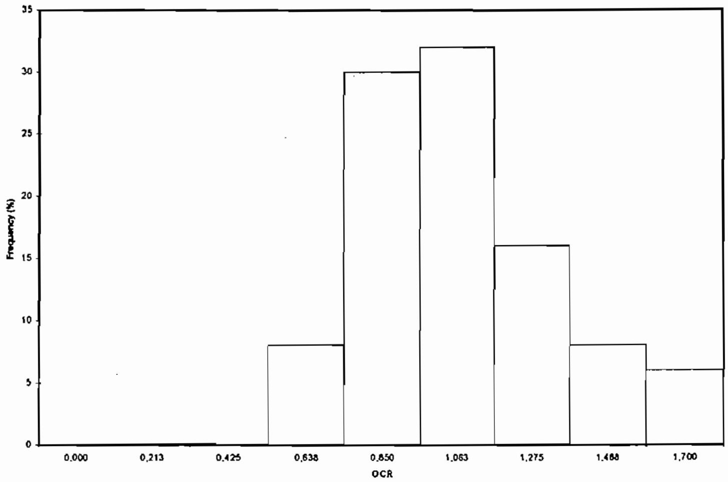

Fig. 2 - OCR calculated values histogram on the 50 samples using Mayne's relation [7]

Finally we can examine the ralations between the angle of shearing resistance and the plasticity index [5], [9]; and the relation between the angle of shearing resistance and the ratio plasticity index-liquid limit [8].

The above mentioned relations are the following:

Kenney [5]: $\sin\phi' = 0.82 - 0.24 \cdot \log PI$;

Muir Wood [9]: $\sin\phi' = 0.35 - 0.7 \cdot \ln PI$

Mayne [8]: $\sin\phi' = 0.656 - 0.409 \cdot \frac{PI}{W_L}$

In Figs. 3 and 4 are plotted the measured data taken form Humphrey and Holtz [4] vs. plasticity index and vs. the ratio plasticity index-liquid limit.

It is important to observe (Fig. 3) the capability of the relations of Mayne [8] and Muir Wood [9] to pass near the point having a plasticity index approximativelly equal to 500. For values of PI < 50 the "dispersion" of data is more evident. In the same Fig. 3 is circled a point that is very far from the two analytical laws.

The Fig. 4 shows, together with measured values, the law from Mayne [8]. Also in this case the dispersion of the measured values respect to the analytical law is strongly evident, but the "fitting" is, in general, acceptable

CONCLUSION

Although we know that "sample" used could not be considered exhaustive (for example, studying the correlation C_c-W_L are involved, essentially, values of W_L between 80 and 110), the aim of this work on one side is to build the basis for a more complex and careful exploration of the empirical correlations that geotechnical engineers use; on the other side the goal is to provoke an urgent research and a further investigation of these correlations in order to make them more reliable.

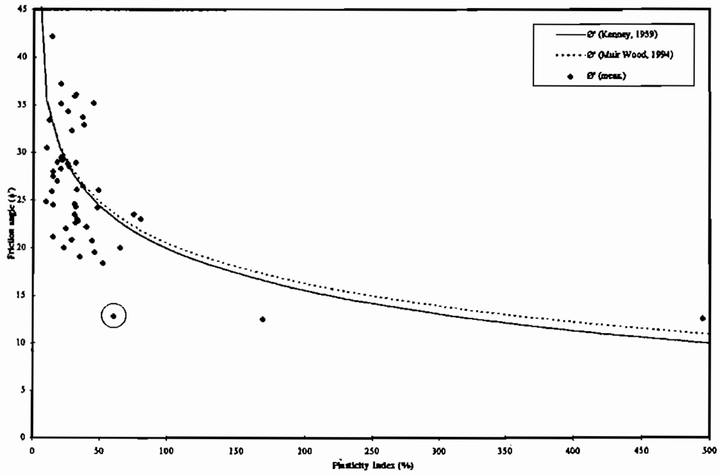

Fig. 3 - Graphic of the correlations (ϕ,PI) by Kenney [5] and Muir Wood [9] with sample's measured values overlaid

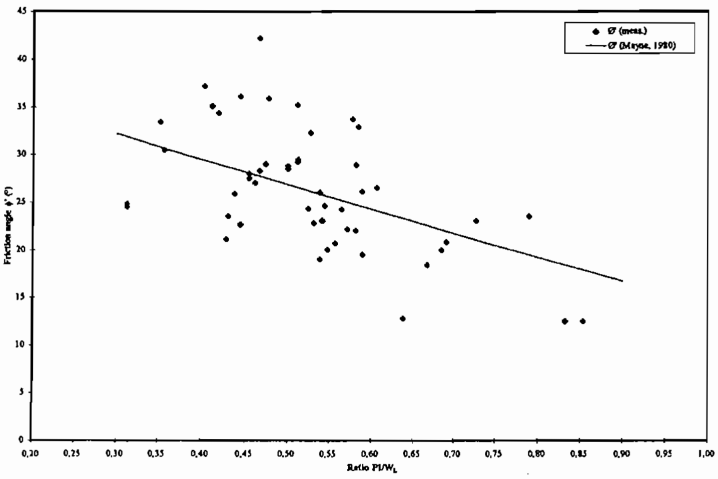

Fig. 4 - Graphic of the correlation (ϕ,PI/W_L) by Mayne [8] with sample's measured values overlaid

REFERENCES

[1] Burghignoli A.,Scarpelli G.: Proprietà dei terreni coesivi italiani. AGI Geotechnical Engineering in Italy, An overview. pp. 199-204, 1985

[2] Carrier W.D.: Consolidation parameters derived from index tests and the properties of remoulded clays. Geotechnique 35, N. 2, pp.211-213, 1985

[3] Cherubini C., Giasi C.I., Guadagno F. Caratteristiche di compressibilità dei depositi pelitici della Piana del Sele. In press on Geologia Applicata e Idrogeologia, 1995

[4] Humphrey D.N., Holtz R.D.: Cap parameters for clayey soils. Numerical methods in geomechanics, Innsbruck. pp. 441-446, 1988

[5] Kenney T.C.: Discussion. Proc. ASCE Vol. 85 n. SM3 pp. 67-79, 1959

[6] Lancellotta R.: Geotecnica. II Ed. Zanichelli - Bologna, 1993

[7] Mayne P.W. Determining OCR in clays from laboratory strength. ASCE Journal of Geot. Eng. 114 N. 1. pp. 27-39, 1988

[8] Mayne P.W.: Cam-Clay predictions of undrained strength. ASCE Journal of the Geotechnical Engineering Division. Vol. 106 GT 11 pp. 1219-1242, 1980

[9] Muir Wood D.: Soil behaviour and critical state soil mechanics. Cambridge University Press, 1994

[10] Nagaraj T.S., Srinivasa Murthy B.R.: A critical reappraisal of Compression Index equations. Geotechnique 36, N. 1, pp. 27-32, 1986a

[11] Nagaraj T.S., Srinivasa Murthy B.R.: Prediction of compressibility of overconsolidated uncemented soils. Journal of Geotechnical Engineering Vol. 112, N. 4, pp. 484-488, 1986b

[12] Skempton A.W.: Notes on the compressibility of clays. Quartely Journal of Geol. Soc. Vol. 100, pp. 119-135, London, 1944

[13] Terzaghi K., Peck R.B.:Geotecnica. UTET, Torino, 1974

CORRESPONDING AUTHORS
Prof. Ing. Claudio Cherubini;
Dott. Ing. Luigi Cucchiararo;
Dott. Ing. Concetta Immacolata Giasi;
Dott. Ing. Francesco Santoro
Istituto di Geologia Applicata e Geotecnica - Politecnico di Bari
Via E. Orabona,4 70125 - Bari - Italy
Fax: +39-80-5460675