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

doi: 10.32075/17ECSMGE-2019-0804

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

Preconsolidation pressure, CPT'u tip resistance, Menard net limit pressure and undrained shear strength.

Contrainte de preconsolidation, résistance de pointe au pénétromètre statique avec mesure de pression interstitielle, pression limite nette au pressiomètre Menard et cohésion non drainée.

J.C. Gress
Professeur à l'Ecole Nationale des Travaux Publics de l'Etat. 1983 – 2012. Reconnaissance et traitement de sols et des roches, Vaulx en Velin, France. Conseiller technique d'Hydrogéotechnique, Goussainville, France.

ABSTRACT: The assessment of relevant preconsolidation pressures σ‘p is often needed in geotechnical design, but it is a major difficulty. Futher ways to do it are then interesting. A first one was given by Mayne. We will propose to improve Mayne‘s approach. In Mayne‘s relation appears a coefficient m. We will show how to assess this parameter through the knowing of VB_{OD} blue methylene value of the total soil. PMT‘s being very often used in France, we have noticed a strong correlation with CPT‘s cone tip resistance, and with undrained shear strength, and we will then explicit their relations with σ‘p.

RÉSUMÉ: La détermination de contraintes de préconsolidation σ‘p pertinentes est souvent nécessaire pour le projet géotechnique, mais c‘est une difficulté majeure. Des moyens complémentaires pour le faire sont de ce fait intéressants. Un premier a été donné par Mayne, proposition que nous proposons d‘améliorer. La relation de Mayne fait apparaître un coefficient m ; ce coefficient peut être déterminé à partir de la valeur de bleu de méthylène VB_{OD} de la fraction granulométrique totale. Ayant enfin constaté une corrélation forte entre la résistance de pointe au pénétromètre statique et la pression limite nette au pressiomètre ainsi que la cohésion non drainée, nous explicitons leurs relations avec σ‘p.

Keywords: preconsolidation pressure, CPT‘u cone tip resistance, Menard PMT‘s limit pressure, undrained shear strength, compression index.

1 INTRODUCTION

When soils have a geological history where consolidation is a major feature, then it is important for fine grained saturated soils to assess preconsolidation pressures through oedometer tests, in particular for a relevant assessment of settlements. The difficulties linked to this goal are known, the major one being to obtain intact samples, another one in France being very often the presence of coarse particles.

It is obvious that it would be very interesting if these parameters could be obtained by parallell ways. It will appear here after that is possible for saturated soils with CPTu's, PMT’s and vane tests results.

2 CORRELATION BETWEEN σ'p AND NET CONE TIP RESISTANCE $q_T - \sigma_{vo}$

Mayne, Reference 6, has given a very interesting formulae allowing an estimation of σ'p knowing cone tip resistance q_T corrected with measured induced waterpressure around the tip:

$$\sigma'p = 0.33\,(q_T - \sigma_{vo})^m \qquad (1)$$

σ'p: total overburden pressure,

m : given by Mayne linked with Robertson behavior index Ic through:

$$m = 1 - \frac{0.28}{1 + \left(Ic / 2.65\right)^{25}} \qquad (2)$$

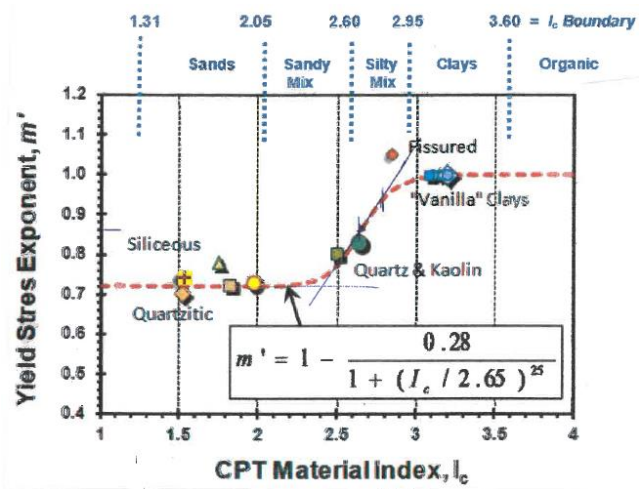

Figure 1. m as a function of Ic (Mayne)

In fact, the oedometer diagramm, Figure 2, shows that $q_T - \sigma_{vo}$ must be linked not only to σ'p, but also to the effective overburden pressure, being in fact linked to the equivalent pressure σ'eq, that should be introduced in a normal consolidation process to obtain the in-situ value of void index = e_{oc} .

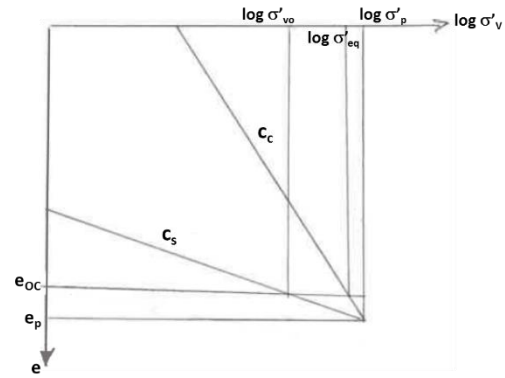

Figure 2. Oedometer diagramm

Figure 2, where Cc is the compression index, Cs the swelling one, ep void index under a pressure of σ'p, shows that:

$$Cc = \frac{e_{oc} - e_p}{\log\left(\frac{\sigma'_p}{\sigma'_{eq}}\right)} \quad and \quad Cs = \frac{e_{oc} - e_p}{\log\left(\frac{\sigma'_p}{\sigma'_{vo}}\right)} \qquad (3)$$

then:

$$\frac{Cs}{Cc} = \frac{\log\left(\frac{\sigma'_p}{\sigma'_{eq}}\right)}{\log\left(\frac{\sigma'_p}{\sigma'_{vo}}\right)} \qquad (4)$$

then:

$$\left(\frac{\sigma'_p}{\sigma'_{vo}}\right)^{\frac{Cs}{Cc}} = \frac{\sigma'_p}{\sigma'_{eq}} \qquad (5)$$

and:

$$\sigma'_{eq} = \left(\sigma'_{vo}\right)^{\frac{Cs}{Cc}} \left(\sigma'_p\right)^{\frac{Cc-Cs}{Cc}} \qquad (6)$$

For a value of $\frac{Cs}{Cc}$ equal to 0.2, (6) becomes:

$$\sigma'_{eq} = \sigma'_{vo}{}^{0.2}\,\sigma'_{p}{}^{0.8} \tag{7}$$

Then it appears that a more relevant way to write (1) is:

$$\sigma'_{vo}{}^{0.25}\,\sigma'_{p} = \left(q_T - \sigma_{vo}\right)^m \ in\ kPa \tag{8}$$

or:

$$\sigma'_{vo}{}^{0.2}\,\sigma'_{p}{}^{0.8} = \left(q_T - \sigma_{vo}\right)^{0.8m} \ in\ kPa \tag{9}$$

m being linked to Robertson index Ic through Relation (2).

3 LINK BETWEEN Ic AND BLUE METHYLENE VALUE VB_{OD}

The blue methylene value is very often used in France to caracterize the plasticity of the soil clayey fraction. Relation (10) between the blue methylene value on the total soil OD and on a fraction od knowing it‘s percentage %d in weight, is very often used (Reference 3):

$$VB_{OD} = \%\,d \times VB_{od} \tag{10}$$

The $VB_{0400\mu}$ of the 0-400µ fraction is well related to liquidity limit W_L and plasticity index PI, knowing %2µ, reference 3.

Through the comparison of VB_{OD} values and Ic for soil categories limits, as figured in Table 1.

Table 1. Comparison between Ic and VB_{OD}

Soil behaviour type	Ic	VB_{OD}	0-400µ Ip
Gravelly sands			
	1.31	0.5	
Clean sands to silty sands			
	2.05	1.5	0.07
Silty sand to sandy silts			
	2.6	2.7	0.12
Clayey silts to silty clays			
	2.95	5.55	0.25
Clays			
	3.12	8.9	0.40
	3.6		

it appears that Ic and VB_{OD} are linked as:

$$Ic \approx 3.6\,\frac{VB_{OD} + 0.4}{VB_{OD} + 1.83} \tag{11}$$

It is here another way to assess m, knowing Ic through VB_{OD} values. Relation (11) will be very useful for PMT‘s and vane tests.

Working on Relations (2) and (11), the comparison between m and VB_{OD} shows that they are linked through a sigmoïde relation, that can be written:

$$m = 0.72 + \frac{0.28}{1 + e^{-1.5(VB_{OD} - 3.35)}} \tag{12}$$

4 CORRELATIONS BETWEEN q_T - σ_{VO} AND MENARD NET LIMIT PRESSURE pl* AND THEN BETWEEN σ'p AND pl*

For saturated soils, it has been already stressed, (Reference 3), that it has been observed a good correlation for french soils between q_T - σ_{vo} and pl* values, through:

$$pl^* = \left(q_T - \sigma_v\right)^{0.8} \text{ in kPa} \qquad (13)$$

due to the comparison during 48 years works between more than a million PMT's and about 200 000 meters of CPT's.

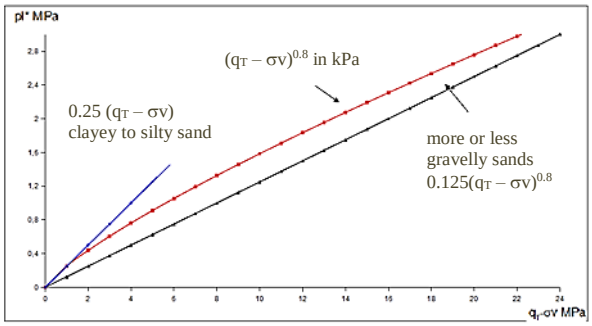

Figure 3. Proposed correlation between q_T - σ_{vo} and pl compared to frequent others*

It is then also possible to assess σ'p through pl* using relation (14):

$$\sigma'vo^{0.2}\sigma' p^{0.8} = pl^{*^m} \text{ in kPa} \qquad (14)$$

5 CORRELATIONS BETWEEN Cu UNDRAINED VANE TEST SHEAR STRENGTH AND pl*

It has been observed in France that Cu and pl* (Reference 3) were linked by the expression:

$$Cu = (pl^*)^{0.7} \text{ in kPa} \qquad (15)$$

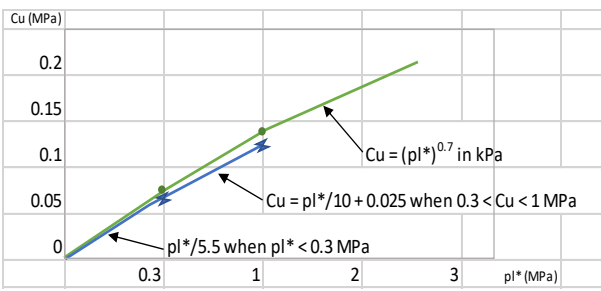

*Figure 4. Correlation between Cu and pl**

Then it can be deduced through (14) and (15):

$$\sigma'_{vo}{}^{0.2}\ \sigma'p^{0.8} = Cu^{m/0.7}$$
$$\text{or } Cu = (\sigma'_{vo}{}^{0.2}\ \sigma'p^{0.8})^{0.7/m} \text{ in kPa} \qquad (16)$$

relation to compare to that of Ladd (Reference 5):

$$Cu = \lambda_{cu}\ \sigma'_{vo}{}^{0.2}\ \sigma'_p{}^{0.8} \qquad (17)$$

The proposed correlation fits with two correlations, suggested by Amar and Jezequel, (Reference 1):

when:

$$pl^* < 0.3MPa : Cu \approx \frac{pl^*}{5.5} \qquad (18)$$

and, when:

$$0.3 < pl^* < 1MPa \quad Cu \approx \frac{pl^*}{10} + 0.025 \qquad (19)$$

pl* in MPa

For Cu > 0.15 MPa, Cu is measured through an unconfined compression test.

6 CORRELATIONS BETWEEN COMPRESSION INDEX Cc, WATER CONTENT W_{OSC} IN AN OVER CONSOLIDATED SATURATED STATE AND WITH σ'p OR q_T - σ_{vo} OR pl*

Knowing now some interesting relations to have complementary ways to assess the values of σ'p, it is also possible to have complementary ways to assess the compression index Cc value, to compare to oedometer results.

Two interesting correlations are well known between Cc and either liquidity limit W_L due to Terzaghi or that of Herrero with water content:

For a sensitivity less than four:

Terzaghi : $Cc = 0.9\,(W_L - 0.10)$ (20)

relation written with slight differences in the values for $W_L < 1$, as:

$$Cc = 0.85\,(W_L - 0.075) \quad (21)$$

Herrero : $Cc = W_N - 0.075$ (22)

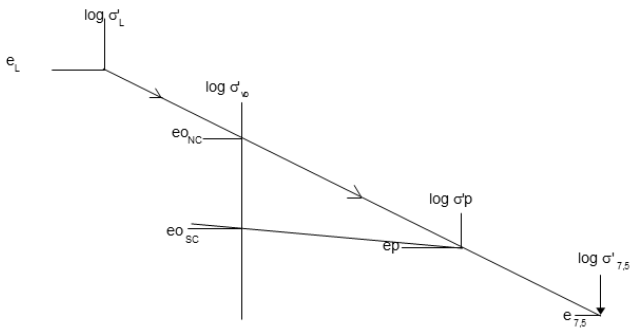

Figure 5. Oedometer diagramm.

Trying to understand why those two different relations give good results and looking at the oedometer diagramme on Figure 5, Cc can be written as:

$$Cc = \frac{e_L - e_{0.075}}{\log \frac{\sigma'_{0.075}}{\sigma'_L}} \quad (23)$$

knowing that e_L is the void index at a watercontent equal to liquidity limit and $e_{0.075}$ at a watercontent of 0.075.

For ɣs in T/m^3, e_L and $e_{0.075}$ can be written as:

e_L = ɣs W_L and $e_{0.075}$ = ɣs x 0.075

with ɣs = 2.7 T/m^3 for non organic soils.

Through the comparison between relations (21) and (23), it appears that:

$\log \frac{\sigma'_{0.075}}{\sigma'_L}$ is probably equal to $\frac{2.7}{0.85} = 3.176$

Knowing that it is often admitted that log σ'_L = 1 if σ'_L in kPa, then log $\sigma_{0.075}$ must be equal to 4.2.

Relation (22) can in fact be writen:

$$Cc = \gamma s \frac{w_{NC} - 0.075}{4.2 - 0.2 \log \sigma'_{vo}} \quad (24)$$

σ'_{vo} in kPa and W_{NC} water content in a normally consolidated state.

Looking at Figure 5, Cc and Cs can be written as:

$$C_C = \frac{e_{ONC} - e_p}{\log \frac{\sigma'_p}{\sigma'_{vo}}} \quad C_S = \frac{e_{OSC} - e_p}{\log \frac{\sigma'_p}{\sigma'_{vo}}} \quad (25)$$

and then:

$$C_C - C_S = \frac{e_{ONC} - e_{OSC}}{\log \frac{\sigma'_p}{\sigma'_{vo}}} \quad (26)$$

and so:

$$W_{SC} = W_{NC} - \frac{Cc - Cs}{\gamma s} \log \frac{\sigma'_p}{\sigma'_{vo}} \quad (27)$$

Relation (24), using Relation (27), leads to:

$$Cc = \gamma s \frac{w_{OSC} - 0.075}{4.2 - \frac{Cs}{Cc} \log \sigma'_{vo} - \frac{Cc - Cs}{Cc} \log \sigma' p} \quad (28)$$

It is observed very frequently that:

$$\frac{Cs}{Cc} \approx 0.2 \; and \; \frac{Cc - Cs}{Cc} = 0.8 \quad (29)$$

and then the expression of Cc becomes:

$$Cc = \gamma s \frac{w_{OSC} - 0.075}{4.2 - 0.2\log\sigma'_{vo} - 0.8\log\sigma' p} \quad (30)$$

which, using Relation (9), can be written:

$$Cc = \gamma s \frac{w_{OSC} - 0.075}{4.2 - 0.8m\log\left(q_T - \sigma_v\right)} \quad (31)$$

with q_T - σ_v in kPa.

As a conclusion complementary ways to assess Cc are now avalaible, though relation (21) knowing W_L or (28) to (31), knowing water content of the investigated soil in an overconsolidated state.

7 CONCLUSIONS

Mayne‘s proposal to assess preconsolidation pressure σ'_p with CPT’s, can be improved introducing the equivalent pressure σ'_{eq} equal to $\sigma'_{vo}{}^{0.2}\,\sigma'_{vo}{}^{0.8}$ instead of σ'_p.

His approach can be extended to PMT‘s net limit pressure pl* and Cu measured through vane tests or unconfined compression tests.

Parallel ways to assess σ'_p are then possible.

But the value of m we chose, is very important for the value of σ'_p we will obtain, having a great influence on the numerical value of σ'_p.

Interesting relations allowing complementary assessment of the compression index Cc are also proposed.

It is then possible to complete oedometer tests results for more relevant studies with results given by CPTs, PMTs and vane tests.

8 REFERENCES

Amar, S., Jezequel, J.F. 1972. Essais en place et en laboratoire sur sols cohérents. *Bulletin de liaison des LCPC*. **58**. Mars-Avril.

Cassan, M. 2005. Le pressiomètre et la résistance au cisaillement des sols, cas particulier des argiles saturées. *50 ans de pressiomètres* **1**. Gambin, Magnan et Mestat (ed.). Presses de l’ENPC/LCPC, Paris.

Gress, J.C. 2012. Corrélations nouvelles pour améliorer la pertinence du diagnostic géotechnique. *Journées nationales de géotechnique et de géologie de l'Ingénieur, Bordeaux.*

Herrero, O.R. 1983. Universal Compression Index Equation. *Journal of Geotechnical Engineering*. Division ASCE **109**, Issue 5.

Ladd, C.C., Foott, R. 1974. A new design procedure for stability of soft clays. *JGED*, ASCE **100**, GT7, 763-786.

Mayne, P.W. 2009. Geomaterial behaviour and testing. *Compte-rendu de la 17ème conférence internationale de mécanique des sols*. Alexandria. IOS Press.

Terzaghi, K., Peck, R.B. 1967. *Soil Mechanics in Engineering Practice*. 2nd Edition, John Wiley and Sons, Inc., New York.

Wikipedia. 2018. *Sigmoïde functions*.