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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.

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ABSTRACT: The assessment of relevant preconsolidation pressures σ'_p is often needed in geotechnical design, but it is a major difficulty. Further 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 V_{BOD} 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 V_{BOD} 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 parallel 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 $q_T - \sigma_{v0}$

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:

$$\sigma'_p = 0.33 (q_T - \sigma_{v0})^m \quad (1)$$

σ'_p : total overburden pressure,
 m : given by Mayne linked with Robertson behavior index I_c through:

$$m = 1 - \frac{0.28}{1 + (I_c / 2.65)^{25}} \quad (2)$$

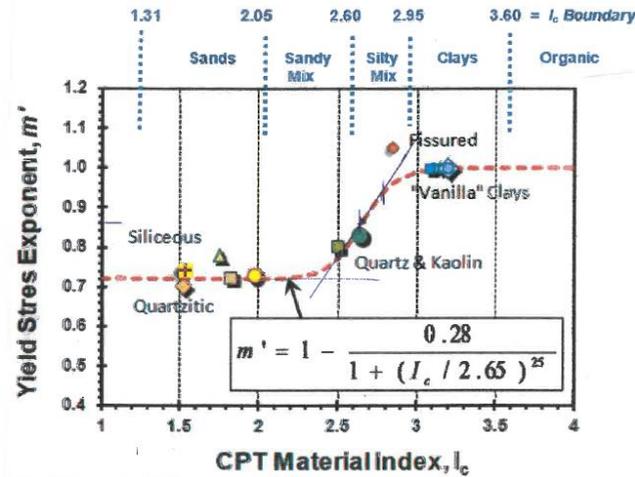


Figure 1. m as a function of I_c (Mayne)

In fact, the oedometer diagram, Figure 2, shows that $q_T - \sigma_{v0}$ 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} .

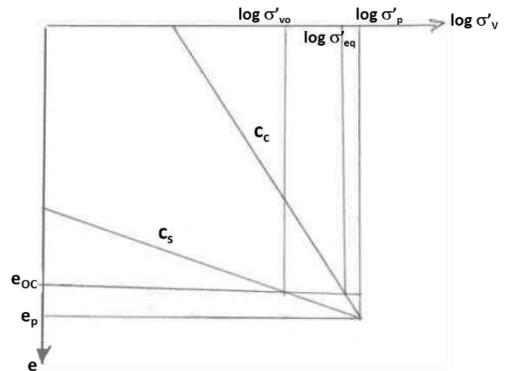


Figure 2. Oedometer diagram

Figure 2, where C_c is the compression index, C_s the swelling one, e_p void index under a pressure of σ'_p , shows that:

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

then:

$$\frac{C_s}{C_c} = \frac{\log \left(\frac{\sigma'_p}{\sigma'_{eq}} \right)}{\log \left(\frac{\sigma'_p}{\sigma'_{vo}} \right)} \quad (4)$$

then:

$$\left(\frac{\sigma'_p}{\sigma'_{vo}} \right)^{\frac{C_s}{C_c}} = \frac{\sigma'_p}{\sigma'_{eq}} \quad (5)$$

and:

$$\sigma'_{eq} = (\sigma'_{vo})^{\frac{C_s}{C_c}} (\sigma'_p)^{\frac{C_c - C_s}{C_c}} \quad (6)$$

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

$$\sigma'_{eq} = \sigma'_{vo}{}^{0.2} \sigma'_p{}^{0.8} \quad (7)$$

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

$$\sigma'_{vo}{}^{0.25} \sigma'_p = (q_T - \sigma_{vo})^m \text{ in } kPa \quad (8)$$

or:

$$\sigma'_{vo}{}^{0.2} \sigma'_p{}^{0.8} = (q_T - \sigma_{vo})^{0.8m} \text{ in } kPa \quad (9)$$

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

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

The blue methylene value is very often used in France to characterize 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):

$$VB_{OD} = \%d \times VB_{od} \quad (10)$$

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

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

Table 1. Comparison between I_c and VB_{OD}

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

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

$$I_c \approx 3.6 \frac{VB_{OD} + 0.4}{VB_{OD} + 1.83} \quad (11)$$

It is here another way to assess m, knowing I_c 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:

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

4 CORRELATIONS BETWEEN $q_T - \sigma_{vo}$ 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 $q_T - \sigma_{vo}$ and pl^* values, through:

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

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

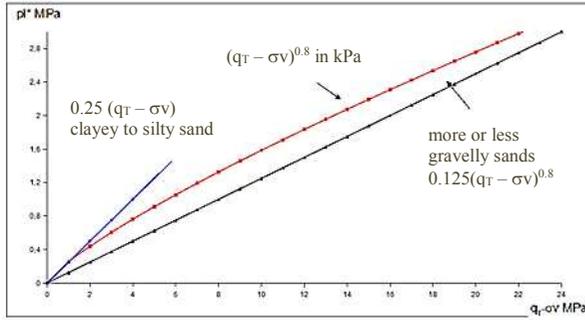


Figure 3. Proposed correlation between $q_T - \sigma_{vo}$ and pl^* compared to frequent others

It is then also possible to assess $\sigma'p$ through pl^* using relation (14):

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

5 CORRELATIONS BETWEEN C_u UNDRAINED VANE TEST SHEAR STRENGTH AND pl^*

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

$$C_u = (pl^*)^{0.7} \text{ in kPa} \quad (15)$$

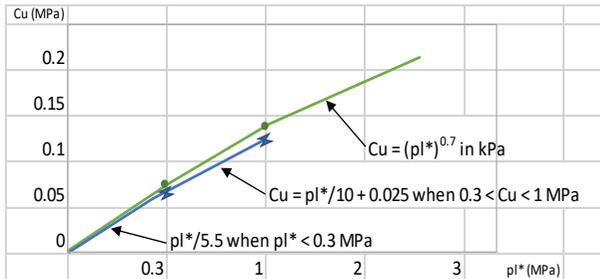


Figure 4. Correlation between C_u and pl^*

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

$$\sigma'_{vo}{}^{0.2} \sigma'p^{0.8} = Cu^{m/0.7} \quad (16)$$

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

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

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

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

when:

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

and, when:

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

pl^* in MPa

For $C_u > 0.15 \text{ MPa}$, C_u is measured through an unconfined compression test.

6 CORRELATIONS BETWEEN COMPRESSION INDEX C_c , WATER CONTENT W_{osc} IN AN OVER CONSOLIDATED SATURATED STATE AND WITH $\sigma'p$ OR $q_T - \sigma_{vo}$ OR pl^*

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

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

For a sensitivity less than four:

$$\text{Terzaghi} : C_c = 0.9 (W_L - 0.10) \quad (20)$$

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

$$C_c = 0.85 (W_L - 0.075) \quad (21)$$

$$\text{Herrero} : C_c = W_N - 0.075 \quad (22)$$

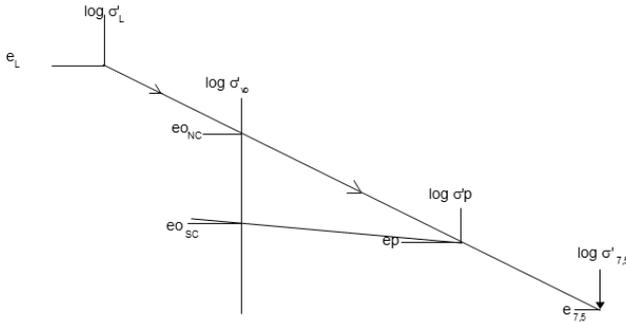


Figure 5. Oedometer diagram.

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

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

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

$$e_L = \gamma_s W_L \text{ and } e_{0.075} = \gamma_s \times 0.075$$

with $\gamma_s = 2.7 T/m^3$ for non organic soils.

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

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

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

Relation (22) can in fact be written:

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

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

Looking at Figure 5, C_c and C_s 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:

$$W_{SC} = W_{NC} - \frac{C_c - C_s}{\gamma_s} \log \frac{\sigma'_p}{\sigma'_{vo}} \quad (27)$$

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

$$C_c = \gamma_s \frac{w_{OSC} - 0.075}{4.2 - \frac{C_s}{C_c} \log \sigma'_{vo} - \frac{C_c - C_s}{C_c} \log \sigma'_p} \quad (28)$$

It is observed very frequently that:

$$\frac{C_s}{C_c} \approx 0.2 \text{ and } \frac{C_c - C_s}{C_c} = 0.8 \quad (29)$$

and then the expression of C_c 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:

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

with $q_T - \sigma_v$ in kPa.

As a conclusion complementary ways to assess C_c are now available, 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 C_u 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 C_c 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.

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