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Development and application in geotechnical engineering of an universal single composed parameter obtained from drilling parmeters

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ABSTRACT: During drilling, variations of the machine's working parameters can be recorded. These parameters give information concerning the response of soil and are often displayed on four to five independent curves. However, their interpretation remains a complex task because of the number of external factors which can influence their value and the number of simultaneously displayed charts. Developing a single composed parameter obtained from these recordings would represent a major step forward for geotechnical engineering in particular in order to clearly and easily identify changes in soil layers. This paper presents how such a parameter K' has been identified, calibrated, tested and validated through everyday geotechnical engineering practice in several study in Paris area. Actually, we have defined a first composed parameter K which has been then normalized considering more than 10 different drilling machines, each one being characterized by a normalization coefficient CM. This way, we obtained for every soil layer encountered in Parisian subsoil a range of values of K' consistent for any drilling machine. This universal single composed parameters may now be used as a reference data in order to identify stratigraphy after drilling in Paris area

RÉSUMÉ: Durant le forage, les variations des paramètres de travail d'une machine de forage peuvent être enregistrées. Ces paramètres fournissent des informations concernant la réponse du sol selon quatre à cinq courbes indépendantes. Cependant, leur interprétation est complexe du fait de la quantité importante de facteurs externes influencant leurs valeurs et la nécessité d'interpréter en simultané toutes les courbes. Développer un paramètre composé unique obtenu à partir de ces enregistrements représenterait une avancée importante pour l'ingénierie géotechnique en particulier afin d'identifier aisément les variations de stratigraphie. Cet article présente la mise au point, la calibration, le test et la validation par différentes projets réalisés en région parisienne d'un tel paramètre K'. Nous avons défini un premier paramètre composé qui a ensuite été normalisé en considérant dix machines de forages différentes, chacune étant caractérisée par un coefficient de normalisation. Ainsi, nous obtenons pour chaque couche de sol rencontré dans le bassin Parisien un intervalle de valeurs du paramètre composé K' applicable qu'elle que soit la machine. Ce paramètre composé universel peut ainsi être utilisé comme une donnée de référence afin de définir la stratigraphie en forage dans la région.

Keywords: Drilling parameters, Database, Range of values, géotechnical enginnering

1 INTRODUCTION

1.1. Drillng Parameters

There are many types of drilling machines used for geotechnical investigations (hydraulic, mechanic,…). Generally, hydraulic machines are used because it has the ability to measure various drilling parameters:

- Pressure on the tool P_0: this is the hydraulic load that is applied on the drilling tool. This parameters can be used to enhance layer of very soft soil in which pressure on the tool is closed to zero
- Advance velocity V_a: it represents the vertical velocity of the tool while drilling. This parameter gives informations about the compacity of the soil, soft soils having high advance speed. (AFNOR, 2014)
- Rotating torque C_r: it represents the pressure that is applied in order to generate the rotation. It gives information about the nature of soil. For example, torque is higher in clayey soils than in sandy soils
- Injection pressure P_i: it is the pressure of the drilling fluid in the borehole. It increases when permeability of the soil decreases
- Back pressure P_r: it represents the pressure in the return circuit. It ranges usually from 1 to 10% of the pressure on the tool
- Rotating velocity of the drilling tool *Vr*

1.2. Choice of a represetative combined parameter

A combined parameter is a single curve which is drawn from all other ones.

Many authors have previously worked on this topic and different combined parameters have been previously defined. Various curves have been compared in (Reiffsteck, 2010).

The most relevant one is certainly issued from Somerton works (Somerton, 1959). He defined an Index S_d such as :

$$S_d = (P_0 - P_r) \times \left(\frac{V_r}{V_a}\right)^{1/2} \qquad (1)$$

We proposed some modifications on this Somerton index in order to be applied to all drilling machines of Technosol. First, parameters such as rotation velocity (unrecorded and almost constant) or *Pr* (not always recorded and neglictible compared to P_0) were ignored. Then, it was essential to add the *Cr* because this parameter gives interesting information about the nature of soil layers. Finally, a factor of 10 was applied in order to obtain parameters ranging from 0 to 10.

So we obtain the expression of parameter K (Frossard, 2016):

$$K = \frac{Po}{Cr\sqrt{Va}} * 10 \qquad (2)$$

First uses of this parameter indicated that it gave relevant indications interfaces between soil layers but the values could not be compared if several machines are used on the same site

To bypass this disadvantage, an improved formula of K was proposed. This improvement is to add a “machine” coefficient CM which would be unique for each machine. This coefficient represents the maximum value of K where pressiometric limit pressure is maximum.

The expression of this modified parameter K‘ is then:

$$K' = \frac{Po}{CM * Cr\sqrt{Va}} * 100 \qquad (3)$$

1.3. CM coefficient

K‘ parameters has been first of all applied on a site with homogenous stratigraphy. Figure 1 shows on the left K curves for 3 different borehoes made with 3 different machines ; on the center is drawn K‘ curves taken into account previously defined CM factors ; on the right is drawn pressiometric limite pressure.

We can see that using CM parameter the combined parameters K‘ curves match perfectly and interface between upper and lower soil layers is easily enhanced.

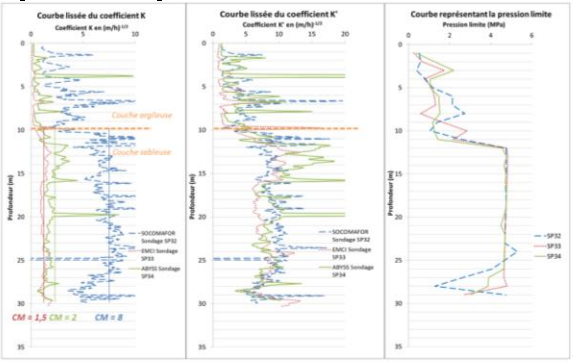

Figure 1 Application of K’ parameter

The following table presents the CM values that have been defined for each drilling machine belonging to Technosol. CM values have been set considering sites where 3 different machines have drilled in the same soil, and then crossing machines between various sites. Results as convincing than those presented on Figure 3 have been obtained for every site.

Table 1. CM values for Technosol drilling machines

Manufacturer	Type	CM
Comacchio	GEO 205 – 1	2
	GEO 205 – 2	1.2
	GEO 305 – 1	4
	GEO 305 - 2	2.6
TEC Systems	Abyss 50	2.3
Socomafor	35	5.3
	50	3.2
	65	1.8

2 APPLICATION OF PARAMETER K‘ IN GEOTECHNICAL ENGINEERING

2.1 K‘ database

Considering that for one defined type of soil in one given site K‘ is unchanged between various machine after CM calibration, we have then compared for every layer encountered in parisian subsoil K‘ curves obtained with various machines in various sites.

Results were once again very convincing. We obtained for every layer K‘ values ranging in the same interval whatever the site and the machine.

In order to illustrate that, we present in this article the example of 3 surveys in 3 different sites concerning the same soil layers: fills, Ludian marls, Saint-Ouen limestone and Beauchamp sands. For these 3 sites, 3 different machines were used:

- Paris, Machine 1, CM=1.6
- Rosny-Sous-Bois, Machine 2, CM=3.2
- Pantin, Machine 3, CM=2

K‘ curves are displayed on Figure 2.

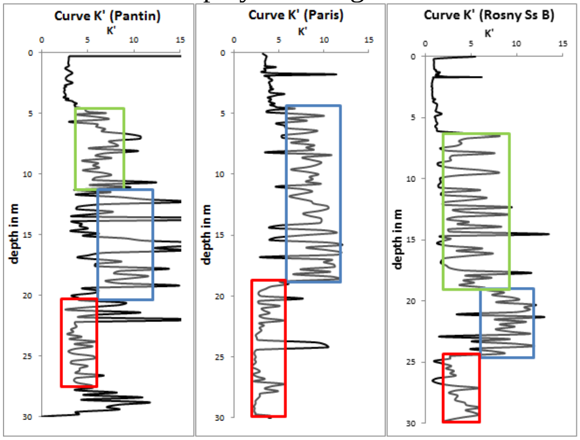

Figure 2 Comparaizon of K’ values for various layers in various sites

The blue rectangle underlines Saint-Ouen limestone layer, where values of K’ oscillate between 6 and 12. The red rectangle shows Beauchamp sands layer, where values of K’ oscillate between 2 and 6. The green rectangle underlines Ludian marls, where values of K' oscillate between 3 and 8. On the top of the surves, we identity fills with K' ranging from 0 and 4.

This charts leads to homogenous K' interval for every soil layer for any site and any drilling machine. K' is then demonstrated to be an universal parameter.

Therefore, considering more than 100 boreholes achieved in 40 sites we have been able to obtain a database of invariant K' values for every soil layer of parisian area.

This database, shown on table 2, presents characteristical K' values for layer and can be used as is a new tool to identifiy precisely every layers encountered while drilling.

Table 2. K' database – Parisian area

Geological layer	K' range
Ancient alluvium	4 to 8
Brie limestone	4 to 9
Green clay	1 to 3
Ludian clayey marls	2 to 5
Ludian calcareous marls	3 to 8
Saint-Ouen limestone	6 to 12
Beauchamp sand	2 to 6

2.2 *Application for enginnering projects – Case 1*

This database is a powerful tool for geotechnical engineering. If geological stratigraphy is known for one given site, for example thanks to a corehole, use of K' while exploiting destructive boreholes will give the precise depth and thickness af each layer all over the site.

Figure 3 illustrates this. In this case, predictible soil layers were : fill materials, ancient alluvium, clayey marls and Saint-Ouen limestone.

Chart in red represents K' next to pressure limit (in orange blocks). Other columns are pressure on the tool (red), rotation torque (pink) and advance velocity (blue).

We note that K' curve fits with pressiometric values.

On the other hand, this figure underlines the fact that it is difficult to exploit simultaneously 3 drilling curves drawn on the 3 charts on the left.

Comparing K' values to the data base allows to identify each layer, layer 1 being fill material: ancient alluvium in layer 2 (K'=4 to 8), clayey marl in layer 4 (K'=2 to 5), Saint-Ouen limestone in layer 5 (K'=6 to 12).
But layer 3 is not identified because it reaches K' values not foreseen in the expected stratigraphy. Referring to the database, no geological formation have such range of value of K'. To determine the type of soil, it's essential to formulate assumptions. In that case, we formulate assumptions with the existence of a rocky gypsum or limestone interbed.

Here is another benefit of the use of K' which allows to underline anomalies.

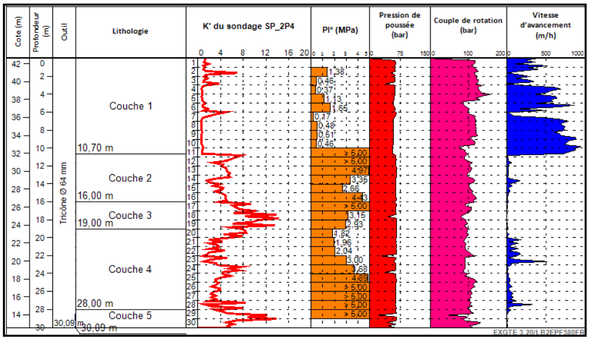

Figure 3 Application of K' in order to identify soil layers

2.3 *Application for engineering projects – Case 2*

The second outgoing project where we have applied the parameter K', is for a geotechnical campaign where about 100 boreholes have been achieved in order to show the depth, thickness and resistance of Brie limestone (*travertin de Brie*).

Only destructive boreholes have been achieved without any corehole or pressiometer test.

We have applied the parameter K’ and we have deduced a lithology and we have compared that with the soil statigraphy indicated by the operator (see Figure 4).

Without K‘ curve, one may have believed in the geological log indicated by the operator (see collumn „*coupe sondeur*“) which indicates Brie limestone from 4.8 m to 15.5 m.

But K‘ curve (on the left) clearly identifies limestone up to tu 10.8m (K‘=4 to 9) then green clay (K‘=1 to 3). The log given by the operator was wrong.

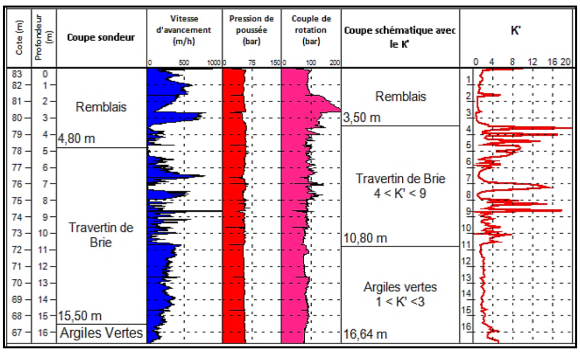

Figure 4 Application of K‘ in order to identify Brie limestone

3 DISCUSSION

Various external factors may influence values of drilling parameters an then K‘.

K‘ range of values as said before are universal provided that drilling conditions are fair and homogenous.

3.1 CM values

In particular, CM coefficient are set for one given machine with its initial preset drilling parameters (such as the flow of the drilling fluid or the initial pressure). Experience indicate that operator almost never change these parameters on their machine. But if one machine is used by another operator these parameters may be changed and then CM value does not apply.

It must be clearly underline here that CM values only apply for one given machine used by one given operator.

The set of CM values is the entire responsability of the company which exploits the machine. It can only be achieved after interpretating many works made by the same operator/machine team, as we did.

Actually, values indicated in table 1 do only apply for machines belonging to Technosol and considering their use by Technosol. Same machines used by aonther company will have different CM values.

3.2 Drilling conditions

Using defective tools could impact drilling parameter and divide advance velocity by a factor up to 2.

Moreover one must keep in mind that K‘ is applicable only for rotating drilling method. It does not apply for roto percussion.

Finally, preset initial drilling parameters should note be changed during drilling.

It is also obvious that drilling parameters recording must be reliable. Any mistake or manipulation error while recording prevent any use of K‘ method.

3.3 Requirements for application of K‘ method

As indicated before, K‘ methods is proved to be very efficient when the expected lithology on site is known. Indeed, expected range values of K‘ for every layer are then set (see table 2) and depth and thickness of layers can be easily obtained.

Restriction concerning the preset of CM coefficient as explained before leads to limit K‘ method application for works where operator/drilling machine team are known and for which CM coefficient has been defined.

3.4 Drawing of K‘ curves

K‘ curves as presented in the prévious examples have been set considering one measurement every 20 centimeter (measures done every centimeter) in order to obtain smooth lines and reduce the impact of local peaks (noise).

Other statiscital methods have been tried and compared. Figure 6 compares K‘ as obtained before to running median values K'_{med} and running average K'_{moy} at a 20 centimeters scale.

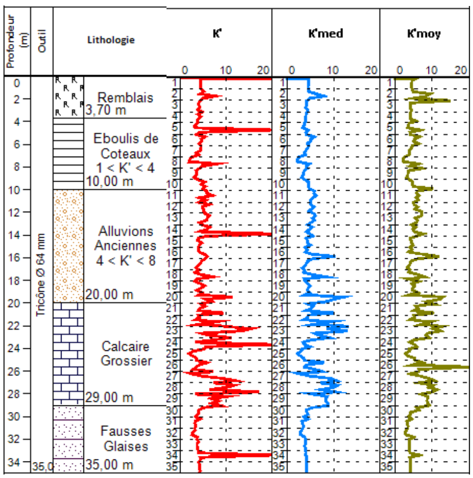

Figure 6 Comparizon of K‘ curves

This comparizon indicaes that running median values leads to smoother curves with a significant noise reduction.

4 CONCLUSION

These works have led to the development of a new geotechnical engineering tool which can simplify geological study, by combining drilling parameters only.

The universality of this combined parameter K’ could ease geological study in several case by doing only destrutive boreholes with a significative save of cost for the contractors.

Now this parameter must be used and tested at a large scale. This is ongoing in Technosol on our everyday geotechnical enginnering projects and a return of experience will be organized in the next months.

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