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Using Pressuremeter Test Results to Estimate Bearing Capacity in the Vicinity of a Slope- Numerical Analysis-

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ABSTRACT

This work consists in using the results of the modeling of the pressuremeter test in the estimation of the bearing capacity near a slope, the proposed basic formulas correspond to a simple configuration of reference, the soil mass being on surface free horizontal and the foundation subjected to a vertically centered load. The most complex cases, and in particular the presence of a slope, are treated by means of reducing coefficients applied to the basic formulas. The main objective of this article is to estimate numerically the characteristics of the pressuremeter test (pressure limit, pressuremeter module) to determine the bearing capacity in the vicinity of a slope. Our contribution is therefore to use a calculation code based on the element method with the contribution of two elasto-plastic laws, namely Mohr-Coulomb and Cam-Clay), with the exploitation of the results of the geotechnical survey carried out. as part of the project on the railway line in the Tissesmilt region (west of Algeria) and finally test the reliability of the results with the use of a statistical study by the approach of the normal law (probabilistic method).

1. Introduction

The design and construction of structures as a train station based on shallow foundations near a slope has become increasingly common, hence the need for reliable methods for the design and

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calculation of these foundations. Several methods have been developed for the calculation of the bearing capacity namely the classical method (c and φ) [1], the methods based on the results of the in-situ tests (the pressuremeter test,) without excluding the numerical methods which are generally based on the finite element method. Geotechnical modeling requires the use of behavior models, the determination of the values of the parameters of this law remains a crucial step for geotechnical modeling. These parameters can be identified from laboratory tests and / or tests in place, either with both types of tests.The main objective of this article is to make a numerical modeling of in situ tests with a calculation code based on the finite elite method, is to do a numerical interpretation of the results of in situ tests during a loading of the soil. For used in the numerical estimation of the bearing capacity, so to test the reliability of the results to find.

2. Theoretical synthesis

2.1. Classical methods

Estimating the bearing capacity of a shallow foundation is one of the major and traditional problems in geotechnical engineering. There are different methods to estimate the bearing capacity of shallow foundations namely:

We find the method (c and φ) is probably the best known method of soil mechanics, with the expression proposed by Terzaghi [1]:

$$q_u = \frac{\gamma B}{2} N_\gamma + cN_c + qN_q \tag{1}$$

N_γ, N_c, $et\ N_q$ These are factors bearing.

For the whole study it is considered that the procedure of the genesis of the slope is the procedure of settlement is therefore the determination of the initial state constitutes (fig .1) .One of the most delicate problems of soil mechanics, the state of stress in a massive soil in place is highly dependent on the history of the solicitations suffered by the massif over time. Finite element modeling of a geotechnical problem within a soil mass therefore raises the problem of the initialization of the stress field [2].

• In the case of a horizontal surface massif, the state of stress is known, it is completely

Determined by the estimate of the pressure coefficient of the lands at rest K_0

• In the case of a massive complex geometry, the state of constraint is difficult to estimates initialization can be done only by numerical simulation of the supposed history

Thus, the presence of a slope the carrying capacity of this complex configuration is afficulated by a minor coefficient. This problem has been

the subject of full-scale tests or centrifuged or normal gravity models. In addition, some authors have developed theoretical methods .For assessing the lift of a running foundation at the edge of a slope. [3] Proposes the minority coefficients (i_β). It is the ratio of the bearing capacity of a foundation established on the edge of a slope to the bearing capacity of the same foundation, established on the same floor with a horizontal surface; it corresponds to the following expression [4]:

$$i_\beta = \frac{[q_u]_{d/_B,\beta}}{[q_u]_{\beta=0}} \tag{2}$$

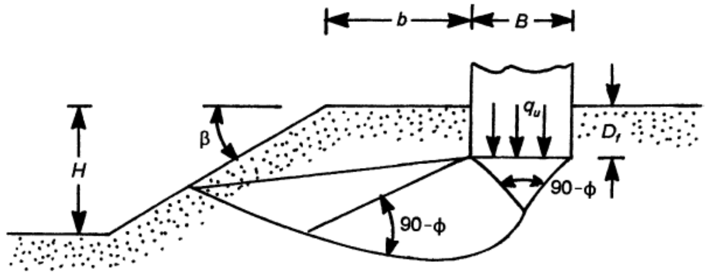


Fig.1. Shallow foundation near a slope [5].

2.2. Empirical methods

This method consists in carrying out the horizontal expansion of a cylindrical probe in a borehole at a given depth, under radial stresses until the rupture of the soil. It makes it possible to obtain a relationship between the stresses. and the horizontal displacements of the borehole, which is a great advantage over other in-situ tests, as it allows the analysis of soil behavior in both small displacements and at break. [6]; thus the contribution of Louis Ménard (the miracle inventor) consisted mainly in defining the pressuremeter characteristics of soils and in developing interpretive rules for the design of foundations using these parameters [7–10] . According to fascicle 62, the estimate of the breaking stress from the limit pressure [11] is in the following form:

$$q_u = q_0 + k_p p_{le}^* \tag{3}$$

3. Digital study

To meet the objectives mentioned above, a calculation code based on the finite element method must be used throughout the study. The problem is treated in plane strain in the plane (O, X, Y), with boundary conditions in displacement: the horizontal displacements are null on the vertical limits of the solid mass, the vertical displacements are null on the base. The geometry and dimensions of the model considered are defined in Figure 2. The massif is subject only to its own weight and has a talus height (H_m = 10 m), whose surface is inclined at an angle (β = 26, 5 °) in relation to the horizontal. The characteristic dimension (d = 20 m) of the model defines the distance to which the boundary conditions are applied.

These dimensions make it possible to consider that the boundaries are sufficiently far removed from the zones of disturbance and that one can neglect the effects of these [12], the construction of the model comprises several stages: the construction of the model, the mesh, the definition of the Boundary conditions and initial conditions are geostatic constraints representing the weight of soil layers with a resting earth thrust coefficient K_0, obtained by the formula of ($K_0 = 1 - \sin \varphi$) [13]. The soil of our study is considered as an infinite, homogeneous, isotropic mass. Its behavior follows two elastoplastic laws with Mohr-Coulomb criterion defined by (E, ν, c, φ, ψ) and Cam-Clay defined by (E, ν, λ, k, M, e_0, p_{co}) [14–16]. As the geotechnical characteristics are grouped in Table 1 these results are obtained from a core sampling carried out at the project site of the railway line,

For the pressuremeter (Figure 4) The mode of deformation of the pressuremeter probe is the plane deformation. In axisymmetric condition, in small deformations in drained conditions (in effective stresses) The soil is free on the vertical walls of the borehole and a vertical displacement is possible on the two vertical boundaries. For loading, a load applied by the probe on the ground This type of loading is applied radially over a length equal to the length of the probe, downhole (Figure 4 and Figure 5).[17].

Table1

Summarizes the geotechnical parameters adopted for the study.

	Parameters	Unit	Silty clay	shallow foundation
Model			Elasto-plastic	Elastic
Mohr-Coulomb	γ	(kN/m^3)	16	
	E	(MPa)	2	40000
	ν	-	0.3	0.3
	φ	(°)	20°	
	C	(kPa)	15	
	ψ	(°)	0^0	
Cam-Clay	λ	-	0,155	
	k	-	0,052	
	M	-	0.70	
	e_0	-	0.680	
	p_{co}	(kPa)	0	

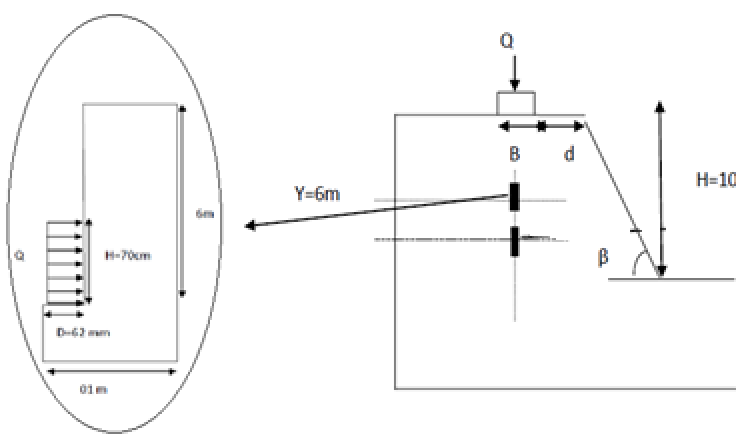
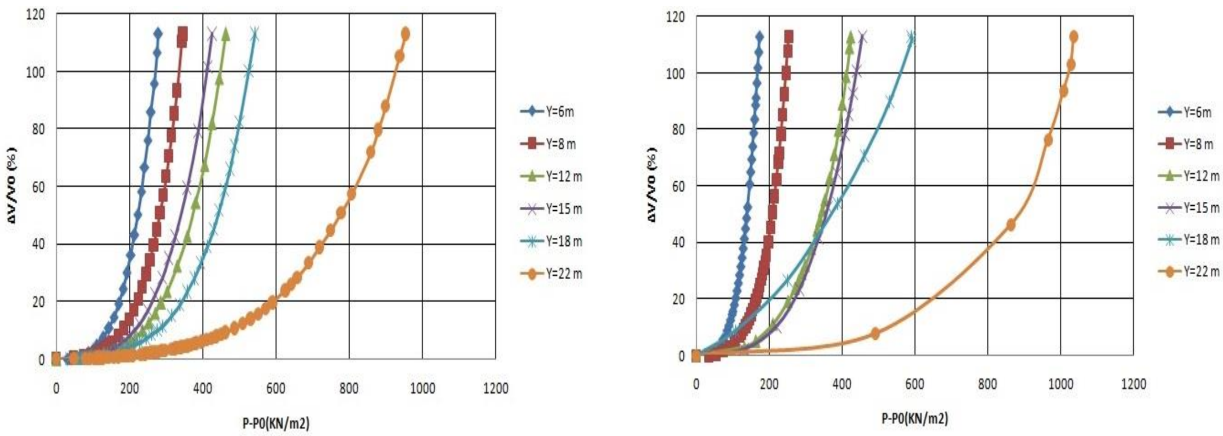
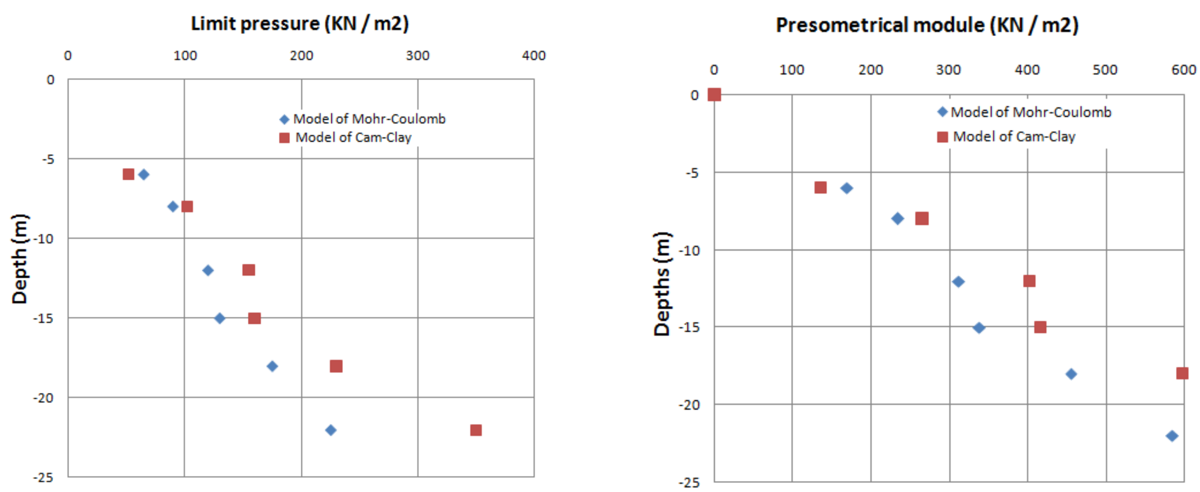


Fig.2. Geometry of the problem



Mohr-Coulomb Cam-Clay

Fig.4. Pressurometric curves -Sloping massif.



a- Limit pressure profile b- Profile of the pressuremeter module

Fig.5. Profiles of pressuremeter characteristics.

3.1. Analysis and discussion

For the pressuremeter test, Figure 3d, represents for the sloping solid mass with the Mohr-Coulomb model, the results of horizontal displacements at the depth (Y = 8 m). This case is important because it will serve as a reference compared to simulations performed in other depths. It can be seen that the horizontal displacement has a proportional variation with the depth and with the variations of the model of behavior; the pressiometric expansion curves obtained for different depths (Y = 6, 8, 12, 15, 18 and 22 m) are shown in Figure 4, for the Mohr-coulomb and Cam-Clay model for a horizontal mass. Pressuremeters will be given in the form ($\Delta V / V_0 = f(p-p_0)$), where ($V_0$) is the initial volume of the probe, (V) the current volume, (p_0) is the initial horizontal radial stress at the level of the probe, and ($p-p_0$) represents the pressure applied in the probe at the loading increment considered. These results are consistent with the conventional

curves of the pressuremeter test [10,18–21], better to put classical references curves have a marked curvature. For high depths, they become quasi-linear, It is found that the limit pressure and the pressuremeter module has a proportional variation with the depth so a variation with the nature of the model behavior of the soil for the model of behavior Mohr-Coulomb has a value larger than for Cam-Clay model. Are shown in Figure 5, which depend only on the depth (Y) at which it is made [10,11].
To find a correlation, between (P_{lim}, E_M) we proceed a study of the histograms of the concerned parameters, (P_l, E_M), in order to check the dispersion of the results for the same nature of the soil consequently the reliability of a test compared to another; for these histograms, the ideal situation is the one that would be closest to the GAUSS random distribution (Normal distribution X N (m, σ) [22] with the following formula:

$$f_X(X) = \frac{1}{\sigma\sqrt{2\pi}} exp\left[-\frac{(X-m)^2}{2\sigma^2}\right] - \infty < X < \infty \quad (4)$$

With m: the mean, σ: standard deviation

- For this type of soil, it can be seen that the histogram of the limiting pressure is close to the ideal situation figure 6; that that of the pressuremeter module moves away from it more with a great dispersion of the results than the histogram of the value (E_M) (figure 7) consequently one can draw a correlations between (P_{limite}, E_M) see table 2.

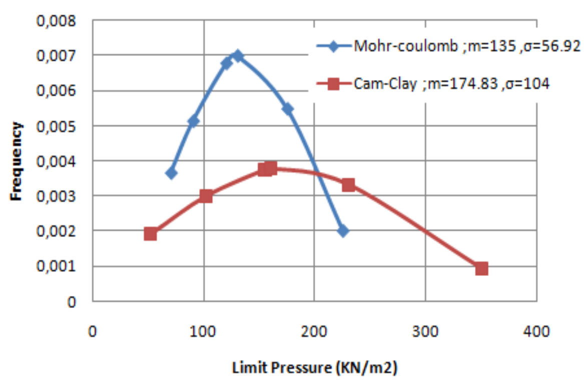


Fig.6. Dispersion of the Limit Pressure

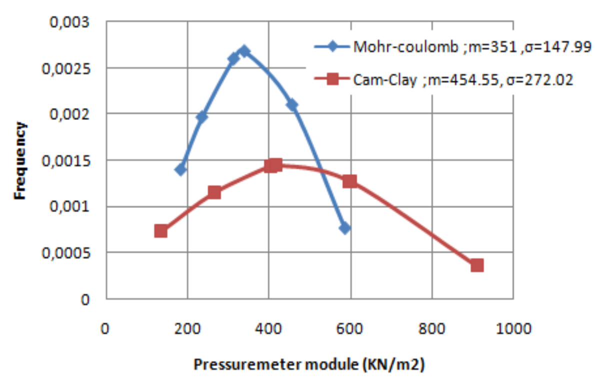
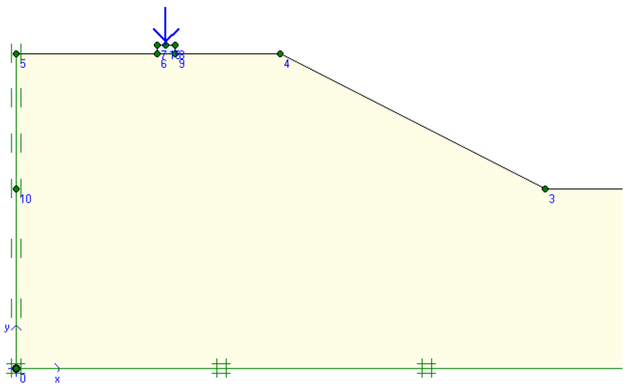


Fig.7. Dispersion of the pressuremeter module

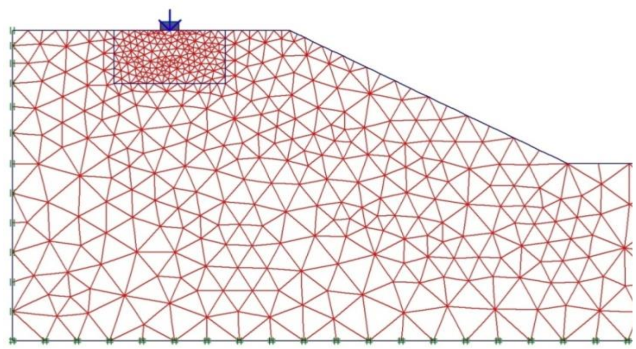
Table 2
Correlations between the limit pressure and the pressuremeter module.

Model	Massive type	Correlations	R^2
Mohr-Coulomb	Horizontal	E_M=2.589P_{lim}-0.003	0.991
	Sloping	E_M=2.595P_{lim}-0.004	0.998
Cam-Clay	Horizontal	E_M=2.637P_{lim}-0.008	0.994
	Sloping	E_M=2.569P_{lim}+0.007	0.998

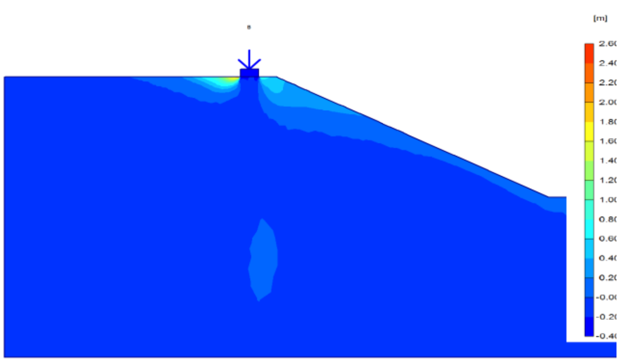
Until this point the numerical estimation of the pressurometric test has been processed, in the second part we will estimate the bearing capacity, the simulations are carried out in the state of flat deformation. Its behavior is linear linear (Figure 8), shows the mechanism of rupture of a shallow foundation under a vertical load .the two versons are brought closer to each other. them which explains the increase of the carrying capacity for a horizontal solid mass than of the other complex configuration like the presence of a slope, After having traced the various curves of the evolution of the carrying capacity, the results are presented in the form of curves giving the relative vertical settlement s / B in (%) according to the average stress under the foundation q. Mohr-coulomb) is found to have a higher bearing capacity than the Cam-Clay model (fine soil). Qualitatively, however, for the shape of the curve (Figure 9) the results of the tests in place can also be used to estimate the load bearing capacity. Equation 3 is used to estimate the pressure-bearing coefficient; So from the different simulations of loading a foundation carried out previously, a numerical lift factor $(kp)_{num}$ is calculated and compared to the values from Fascicle 62, $(K_p)_{issu}$. The results compiled in Table 3, show that the values of $(k_p)_{num}$ are strongly overestimated with respect to $(K_p)_{issu}$ .and to find correlations between the bearing capacity (q_l) and the limiting pressure (P_{lim}) See Table 4



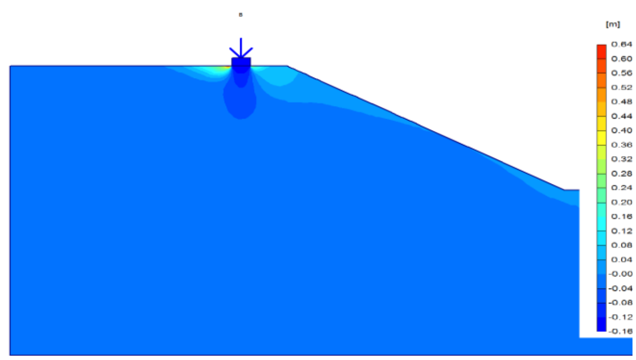
a- Boundary condition and loading



b-Optimal Mesh and Loading

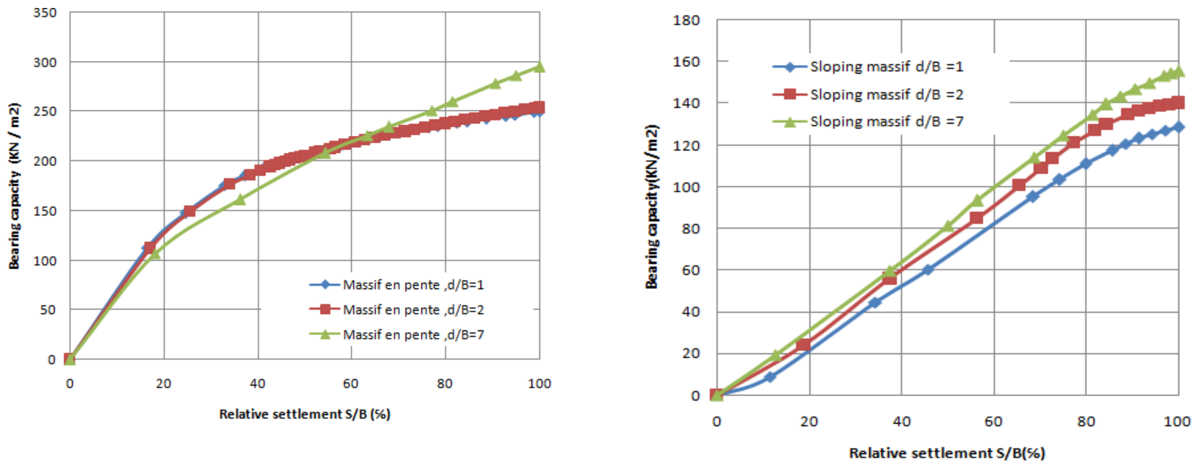


c- Mechanism of the rupture under shallow foundations d/B=1



d- Mechanism of the rupture under shallow foundations d/B=2

Fig.8. Modelization of shallow foundations.



a- Mohr- Coulomb Model b- Cam-Clay Model

Fig.9. Evolution of bearing capacity.

Table 3
Digital estimation of the lift factor of the pressuremeter test.

		Mohr-Coulomb	Cam-Clay
	d/B		
bearing capacity	1	594	487
	2	636	524
	7	730	590
P_{limite}		464	450
$(K_p)_{num}$	1	1.28	1.08
	2	1.37	1.16
	7	1.57	1.31
$(K_p)_{issu}$		1.22	1.22

Table 4
Correlations between limit pressure and bearing capacity.

Model	Massive type	Correlations	R^2
Mohr-Coulomb	Sloping	q_l =127-0.599P_{lim}	0.962
Cam-Clay	Sloping	q_l =198.5-1.05P_{lim}	0.937

4. Conclusion

This article is devoted to two main themes, the first of which is a theoretical synthesis on:

- **Ménard pressuremeter test**
- **Estimated bearing capacity**

And the second axis a numerical modeling. in situ tests the determination of the characteristics of pressuremeter tests (Pl, E_M) According to these results, we can see:

- we find that the horizontal displacement has a proportional variation with the depth and with the variations of the model of behavior
- The results are consistent with the conventional curves of the pressuremeter test from the point of view of quality (curve shape). The curves have a marked curvature. For high depths, they become quasi-linear
- As well as the limiting pressure and the pressuremeter module for the Mohr-Coulomb behavior model has a larger value than for Cam-Clay model; and a proportional variation with the depth
- it can be seen that the vertical displacement has a proportional variation with the depth and with the variations of the soil behavior model
- The histogram method and the GAUSS random distribution. (Normal distribution N (m, σ) among the best method for testing reliability and correlating different parameters
- the bearing capacity has a Mohr-Coulomb behavior model variation has a greater value than for Cam-Clay model
- the values of $(kp)_{num}$ are strongly overestimated with respect to

$(K_p)_{issu}$

It is clear that this result still requires improvement to be able to make practical conclusions in relation to the practice.

Notations

q_u	bearing capacity
B	width of foundation
γ	density of the soil;
q	vertical overload;
c	cohesion
q_0	total vertical stress at the base of the foundation
k_p	pressuremeter lift factor
P^*_{le}	equivalent net limit pressure

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