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Tensile pile calculation

Calcul d'un pieu en traction

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ABSTRACT: Pile calculation is particularly complex when it's necessary to consider traction resistance. The French Standard for pile design NF P 94 262 describes two methods that we will analyze and compare to define their relevance and limits of application. These two methods will also be compared to a numerical calculation to determine whether the mechanisms highlighted by numerical modelling are consistent with the two analytical approaches.

RÉSUMÉ : Le calcul des pieux devient particulièrement complexe lorsqu'il est nécessaire de prendre en compte la résistance à la traction. La norme NF P 94-262 décrit deux méthodes de dimensionnement que nous allons analyser et comparer afin de définir leur pertinences et limites d'application. Ces deux méthodes seront également comparées à une modélisation numérique afin de déterminer si les mécanismes mis en évidence par une modélisation numérique aux éléments finis sont bien cohérents avec les deux approches analytiques.

KEYWORDS: tension, tensile, cone, pile

1 INTRODUCTION

The mechanisms implemented during the mobilization of a tensile pile involve the weight of the mobilized soil and the soil/pile friction. The calculation of the bearing capacity of a pile must therefore take into account each of these two parameters and their interaction. The weight of the mobilized soil volume becomes a resistance that must be calculated in order to compare it to the applied tensile stress.

This paper aims to study the dimensioning methods proposed by the French Standard for pile design NF P 94-262 standard, to compare them with each other, but also with finite element modeling in order to determine their relevance and limitations. We will also detail some particular points such as the calculation of a pile network and the application of approach 2 for yield design.

2 NF P 94 262 DESIGN METHOD

The sizing method of the NF P94-262/A1 July 2018 standard presents two approaches that can be used without restrictions whatever the situation (except for diameter < 300 mm where yield design is mandatory).

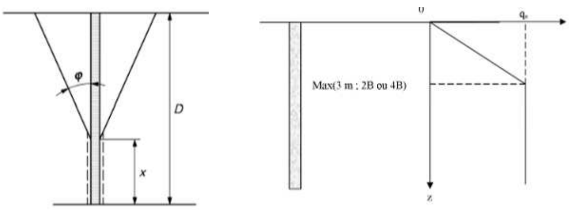


Figure 1. Yield design Linear reduction approach

2.1 *Interpretation of the yield design*

Approach 1 consists in a calculation of the resistance brought by the weight of the soil cone mobilized by the pile when it is put in tension. The value x (figure 1) is determined by the analysis of the depth at which the resistance brought by the increase in the weight of the cone volume becomes greater than the one brought by the new mobilized friction (cf. P.Vezole (Revue Française de Géotechnique, n°98, p47-62)). Due to the conical expansion, this variation of the bearing capacity is not linear with the depth.

2.2 *Interpretation of the linear reduction approach*

The much more simplistic approach 2 assumes a linear increase in friction near the surface. This approach do not depend on the water level and the density of the soil in place. This method leads to a linear reduction between the surface and max(3m ; 2B) in a cohesive soil and max(3m ; 4B) in a granular soil.

3 COMPARISON BETWEEN YIELD DESIGN AND 3D NUMERICAL CALCULATION

In order to verify the formulas of bearing capacity at rupture, we performed a comparison with a finite element software, Plaxis 3D. To do so, an isolated pile is modeled using an "Embedded-beam" element and a displacement is imposed at the head of the pile. The effort mobilized by Plaxis to generate this deformation is then retained.

The soils are modeled in GHS ("Generalized Hardening Soil Model") and the pile considered is a pile made with a CFA ϕ620 mm. The water table is considered at the surface.

Because the calculation aim at comparing failure calculation method and the Plaxis 3D results, main data for this calculation are γ_h, γ', c, φ and qs. Modulus is secondary.

We will present the shape of the ground mobilized in Plaxis 3D during the pile lifting. It is directly representative of the mixed behavior of the mobilized resistance, both in terms of the resistance brought by the soil weight and the friction along the pile.

3.1 *Interpretation of the yield design*

We will consider the following assumptions :

Table 1. Considered parameters

Soil	qs* (kPa)	c (kPa)	φ (°)	γ_h (kN/m3)	γ' (kN/m3)
Soft Clay	51	5	20	17.0	8.0
Stiff Clay	62	15	20	17.0	8.0
Marl	133	30	30	20.0	10.0
Sand	75	0	30	17.0	9.5
Gravel	130	0	38	19.0	11.5

* : qs correspond to the considered friction between the pile and the soil

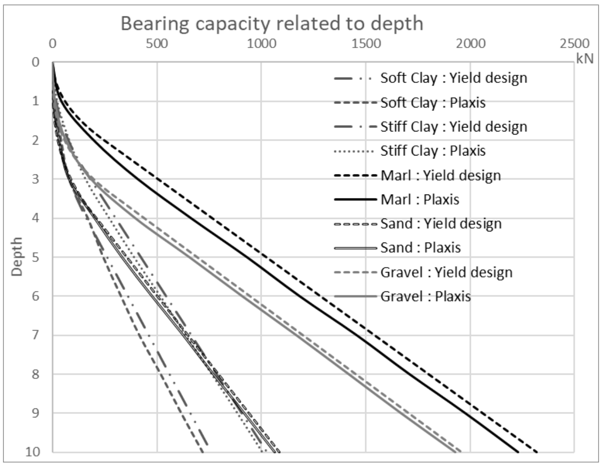


Figure 2. Bearing capacity related to depth (Plaxis and Yield design approach)

Plaxis 3D calculations show an almost perfect correspondence with the yield design for all the types of soils tested: the yield design seems very realistic and can therefore be considered as a reference approach.

3.2 *Comparison of ground mobilization*

The following figures show the different mobilized soil volume shapes after a B/10 imposed displacement (B = diameter of the pile).

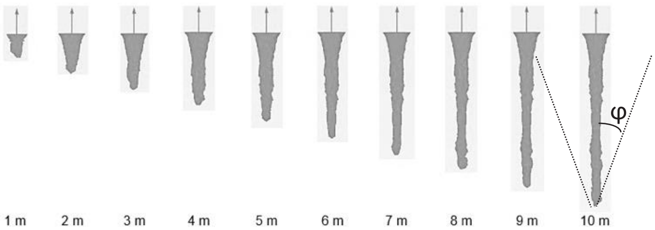


Figure 3. Deformation of the soil around the pile with the depth of the pile in the case of soft clay

Table 2. Considered characteristics.

Soil	pl (MPa)	qs (kPa)	c (kPa)	φ (°)	γ (kN/m3)	γ' (kN/m3)
Soft Clay	0.5	51	5	20	17.0	8.0

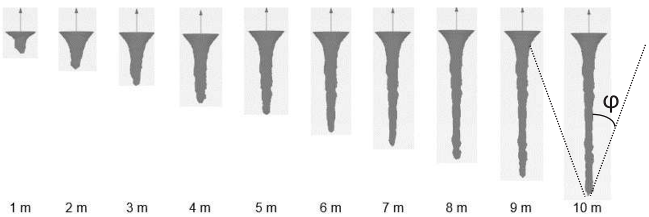


Figure 4. Deformation of the soil around the pile with the depth of the pile in the case of stiff clay

Table 3. Considered characteristics.

Soil	pl (MPa)	qs (kPa)	c (kPa)	φ (°)	γ (kN/m3)	γ' (kN/m3)
Stiff Clay	1.0	62	15	20	17.0	8.0

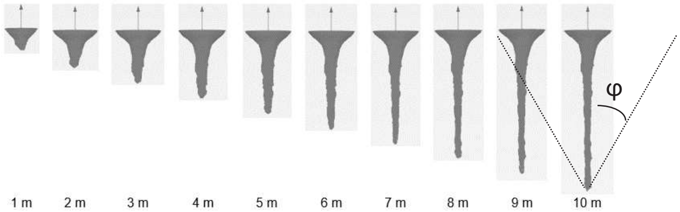


Figure 5. Deformation of the soil around the pile with the depth of the pile in the case of marl

Table 4. Considered characteristics.

Soil	pl (MPa)	qs (kPa)	c (kPa)	φ (°)	γ (kN/m3)	γ' (kN/m3)
Marl	1.0	133	30	30	20.0	10.0

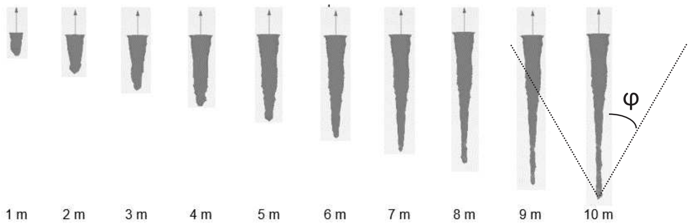


Figure 6. Deformation of the soil around the pile with the depth of the pile in the case of sand

Table 5. Considered characteristics.

Soil	pl (MPa)	qs (kPa)	c (kPa)	φ (°)	γ (kN/m3)	γ' (kN/m3)
Sand	0.8	75	0	30	17.0	9.5

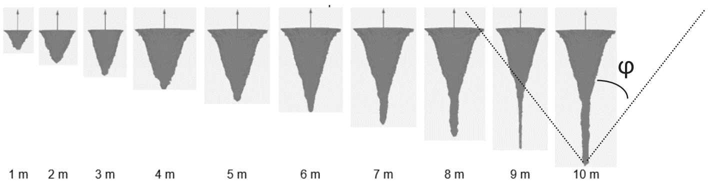


Figure 7. Deformation of the soil around the pile with the depth of the pile in the case of gravel

Table 6. Considered characteristics.

Soil	pl (MPa)	qs (kPa)	c (kPa)	φ (°)	γ (kN/m3)	γ' (kN/m3)
Gravel	2.0	130	0	38	19.0	11.5

The evolution of the ground deformation around the pile shows a strong disparity with the theory since the cone angles obtained are much lower than the friction angles. Nevertheless, the mix behavior (cone then shaft friction) described by Vezole is quite clear. This difference can certainly be explained by the fact that the ground movements are not directly representative of the soil loads. This observation is consistent with the comment of TA2020 in §G.3.1 which tells us that "the volume of influence is a calculation process and does not physically correspond to the volume of ground displaced at the time of the pullout of an anchor".

4 COMPARISON BETWEEN YIELD DESIGN AND LINEAR REDUCTION APPROACH

In this paragraph, we will compare the two approaches for different homogeneous soil types and different water levels. We consider a pile of variable length between 0 and 10 m made with the hollow auger ϕ620 mm in infinite mesh (isolated pile). The bearing capacity calculations are performed without a safety factor (limit load). We will also compare the results obtained without taking into account any reduction in traction. The results are compared in terms of gross bearing capacity or bearing capacity ratio (bearing capacity 1/bearing capacity 2) between 2 calculation methods.

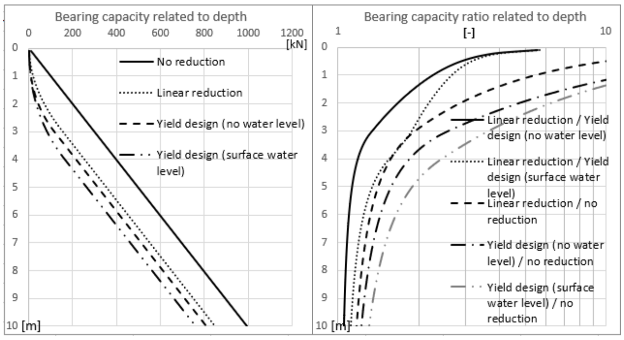


Figure 8. Deformation of the soil around the pile with the depth of the pile in the case of soft clay

The load-bearing capacity obtained using the yield design is much lower than that obtained using the linear reduction method (Δ≈90 kN with water and Δ≈40 kN without water).

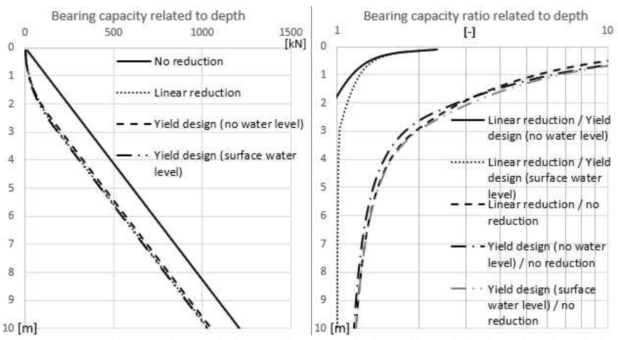


Figure 9. Deformation of the soil around the pile with the depth of the pile in the case of stiff clay

The bearing capacity obtained using the yield design is almost identical to that obtained using the linear reduction method, with or without water.

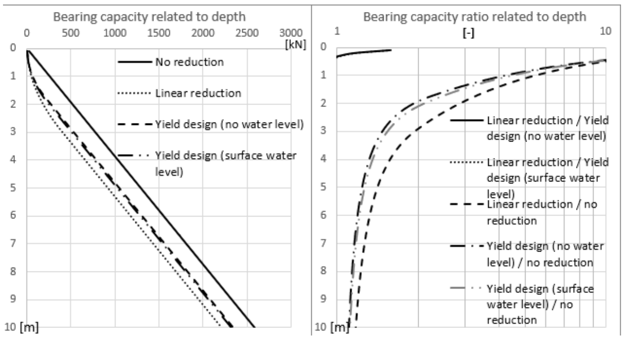


Figure 10. Deformation of the soil around the pile with the depth of the pile in the case of marl

The bearing capacity obtained using the yield design is higher than that obtained using the linear reduction method (≈105 kN with water and ≈125 kN without water).

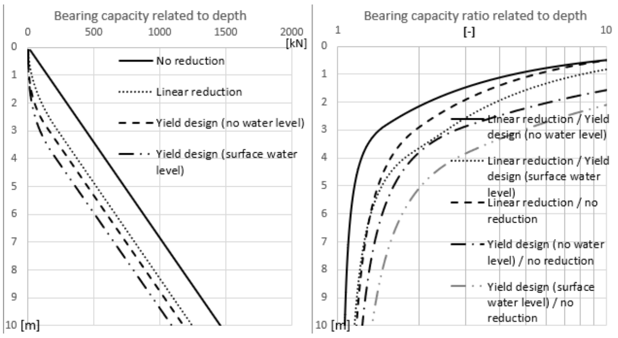


Figure 11. Deformation of the soil around the pile with the depth of the pile in the case of sand

The load-bearing capacity obtained using the yield design is much lower than that obtained using the linear reduction method (Δ≈160 kN with water and Δ≈70 kN without water).

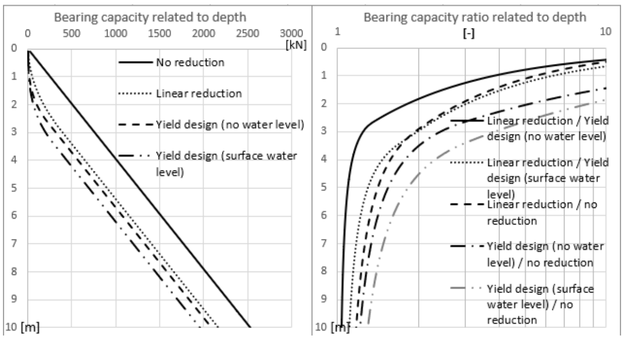


Figure 12. Deformation of the soil around the pile with the depth of the pile in the case of gravel

The load-bearing capacity obtained using the yield design is much lower than that obtained using the linear reduction method (Δ≈205 kN with water and Δ≈80 kN without water).

The analysis of Figures 8 to 12 shows that the linear reduction approach provides a good approximation to the yield design in medium compacted cohesive soils.

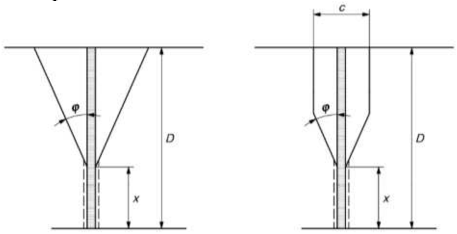
In soft cohesive soils as well as in friction soils, the linear reduction method seems to overestimate the bearing capacity compared to the yield design considered here as a reference (§3.1). On the contrary, in good compactness cohesive soils, the linear reduction method appears to be unfavorable.

Also, the presence or not of the surface water table leads to a significant difference between the two methods.

In any case, it appears that the ratio between resistance with and without taking into account one or the other approach is more important for shorter piles. For example, for a 5.0 m long pile this ratio is about 1.5 to 2.0 compared to a calculation without reduction. It is therefore essential to always take into account one or the other of the approaches for reducing the bearing capacity.

5 FINITE GRID CONSIDERATION

Within a finite network of piles the soil cones will potentially meet as shown in the figure from NF P94-262 / 2nd edition January 2013 presented below.



Légende : x : longueur sur laquelle le frottement axial de la fondation profonde peut être considéré – c : longueur de la maille du réseau de fondations profondes

Figure 13. Estimation of resistance within a pile network

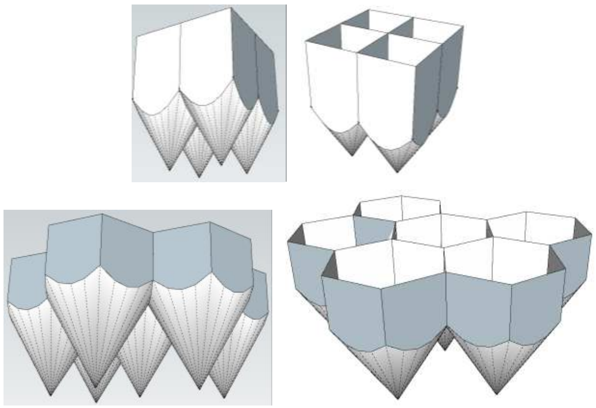


Figure 14. Square mesh and triangular mesh

In the part above the cone, no shear stress is possible. Only the weight of the soil volume can provide any resistance. The 3D view allows to visualize the passage from an independent cone behavior to that of a regular mesh.

The linear reduction method does not allow taking into account a finite mesh (absence of parameter in the formula) and thus appears as unsuitable because it does not allow taking into account the cone clustering zone limiting the resistance of the pile network to the weight of the mobilized land alone.

6 SAFETY FACTORS DISCUSSION

In an approach 2, safety factors are applied to resistance. In a finite grid that means that the resistance brought by the part above the cone is reduced even if the only variable is weight. That direct application of the approach 2 is therefore very conservative.

A solution to get better results and keep the approach 2 would be to use a transition from an approach 3 type c and phi calculation to an approach 2 type resistance-reduced calculation. It could be done this way:

- Determination of the volume of a cone from the angle φk of height H ;
- Application of the safety factor of the considered load case previously determined ;
- Retro calculation of the cone friction angle φd of height H allowing to find the reduced volume.

In the form of an equation we have :

$$\tan(\varphi_d) = \frac{\tan(\varphi_k)}{\sqrt{SafetyFactor}} \qquad (1)$$

$$c_d = \frac{C_k}{SafetyFactor} \qquad (2)$$

This formula allows an integration of the safety factor into the conic part only without having a reduction in the part above the cone.

7 CONCLUSION

Comparative tensile bearing capacity calculations show several points:

- The application of one or the other of the dimensioning methods (yield design or linear reduction) is essential and its non-application leads to a very important overestimation of the resistance;
- The yield design is more complete than the linear reduction approach because it is also applicable to pile networks;
- Bearing capacity calculations are consistent with Plaxis 3D results;
- The calculations of bearing capacity with yield design, although integrating c and phi close to an approach 3, are quite applicable to approach 2 calculations because it is possible to make a link between classical resistance safety factors and friction angles and cohesions. The variation of the qs value will influence the cone proportion in the bearing capacity calculation;
- Comparative analysis of the bearing capacity results suggests that the linear reduction method gives good results in the case of isolated piles in cohesive soils of medium compaction.

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