Proceedings of the XVIII ECSMGE 2024
GEOTECHNICAL ENGINEERING CHALLENGES
TO MEET CURRENT AND EMERGING NEEDS OF SOCIETY

ISBN 978-1-032-54816-6
DOI 10.1201/9781003431749-100

Direct design method of shallow foundation based on in situ tests results, application to dynamic cone penetrometer

Méthode de conception directe des fondations peu profondes basée sur les résultats des essais in situ, application au pénétromètre dynamique

T.A. Luong
Sol Solution, Riom/Université Gustave Eiffel, Champs-sur-Marne, France

P. Reiffsteck*, F. Szymkiewicz
Université Gustave Eiffel, Champs-sur-Marne, France

M. Benz-Navarrete
Sol Solution, Riom, France

philippe.reiffsteck@univ-eiffel.fr

ABSTRACT: The University G. Eiffel has built a light surface foundation test station to perform loading test campaign on experimental sites. This paper presents the test campaigns on shallow foundations carried out to failure with the contribution of optic fibre strain measurement in ground mass. Prediction of bearing capacity may be realized with direct design method based on limit resistance of in situ tests. Several methods based on limit pressure, static and dynamic penetration resistance and SPT blow count will be compared. The results are qualified with a database of 160 load tests with detailed ground investigation. This paper presents a simple, economic, and sound design method that could be easily implemented worldwide, based on a Dynamic Penetration Test (DPT) device.

RÉSUMÉ: L'Université G. Eiffel a construit une station d'essais de fondations superficielles légères pour réaliser des campagnes d'essais de chargement sur des sites expérimentaux. Cet article présente les campagnes d'essais sur les fondations superficielles menées jusqu'à la rupture avec l'apport de la mesure de déformation par fibre optique dans la masse du sol. La prédiction de la capacité portante peut être réalisée avec une méthode de conception directe basée sur la résistance limite des essais in situ. Plusieurs méthodes basées sur la pression limite, la résistance à la pénétration statique et dynamique et le nombre de coups SPT seront comparées. Les résultats sont qualifiés à l'aide d'une base de données de 160 essais de charge avec une étude détaillée du sol. Cet article présente une méthode de conception simple, économique et solide qui pourrait être facilement mise en œuvre dans le monde entier, basée sur une nouvelle génération d'appareils d'essai de pénétromètre dynamique (DPT).

Keywords: Shallow foundation; direct design method; ground investigation; penetration test.

1 INTRODUCTION

The design of shallow foundations is carried out within the framework of Eurocode 7 using two main methods. The first, based on laboratory tests, requires the angle of friction to be determined (Terzaghi and Peck, 1948). This is often determined indirectly from in situ tests by correlation which may be a source of uncertainties. The second one based on the assumption of a similarity of the failure mechanism observed under the shallow foundation and during in situ test, propose a direct calculation using the equivalent resistance of the soil estimated using this test under foundation and the bearing capacity.

This paper describes the shallow foundation tests carried out by the Univ. G. Eiffel/IFSTTAR and the direct design method developed on the basis of the results obtained during the study and those in the database collected in the bibliography. The method derived from the database is discussed.

2 SHALLOW FOUNDATION DATABASE

The development of methods for the design of shallow foundations has always been based on the analysis of test campaigns involving the loading of shallow foundations by dedicated structures. Numerous national research bodies and universities have undertaken parametric test campaigns on sites of various types (Table 1). A complete summary of these tests was produced by Canépa and Garnier

(2004) for the symposium on surface foundations organised by the LCPC in 2003. The tests listed in Table 1 may have varied in their protocol, but follow more or less the same test procedure.

Table 1. Some tests listed in database.

Country	Site	Soil class	Reference
Thaïland	Bangkok	Soft clay	Brand et al,(1972
Irland	Belfast, Kinnegar	Clayey silt	Lehane (2003)
UK	Bothkennar Cowden Shellhaven	Marine soft clay	Jardine et al, (1995) Lehane et Jardine (2003)
Brasil	Porto Alegre	residual soil	Consoli et al, (1998)
Germany	DEGEBO	Sand and coarse sand	Muhs and Weiß (1971)
Koweit	Koweit city	Silty sand	Ismael (1984)
Australia	Shenton Park, Perth	Sand	Lehane et al. (2008)
Portugal	Porto	Silty sand and saprolitic clay	Viana da Fonseca (2001)
Norway	Haga	Firm clay	Andersen and Stenhamar (1982)
Canada	Ottawa	sand	Shields and Bauer (1975)
USA	Texas A & M FHWA	Silty sand Sand clay	Briaud and Gibbens (1999) Lutenegger and de Groot (1995
Sweden	Kolbyttemon Tornhill Vagverket Vattahammar	clay till silt	Bergdahl, et al., (1985) Larsson (2001) Larsson (1997)

Some complementary tests are needed to add some configuration (eccentricity, cyclic solicitation), soil types.

2.1 Shallow foundation loading test

The foundation or plate loading test consists of measuring the settlement corresponding to a succession of load steps applied to the soil by the plate. The test is carried out using the device arrangement shown in Figure 1.

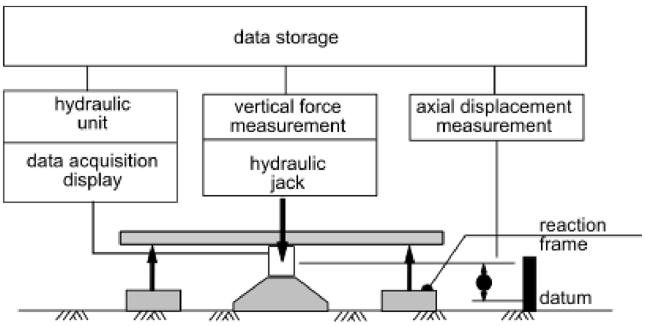

Figure 1. Loading test equipment.

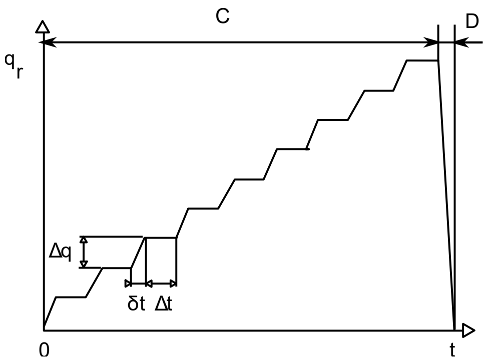

Figure 2. Loading program.

The test is continued:

- either until the ground is punched, conventionally defined as B/10,
- or to the limit of the reaction device.

Each loading stage is kept constant until the curve representing settlement as a function of the logarithm of the time of application is linear, or for 30'. The settlement is measured using comparators uniformly distributed around the plate, the attachment points of which are fixed to a non-deformable frame resting on the ground at points that must remain immobile during the test. Figure 2 and 3 gives example of test realised in this research to increase test results in database.

Figure 3. Test on sandy site.

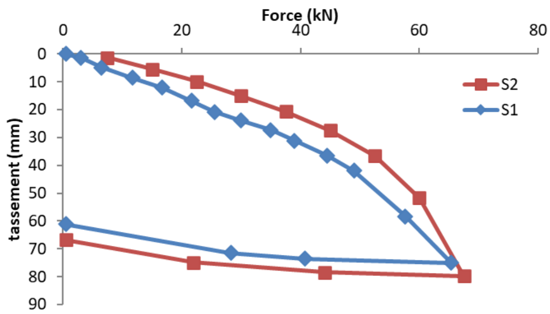

Figure 4. Test result on a soft clay site.

3 DIRECT DESIGN METHOD

This method, standardized in France since the seventies was developed by Menard mainly for the pressuremeter and adopted in French design rules for

CPT since 1988, and also proposed in other studies (Lehane, 2019). It has been extended in this research, to dynamic and standard penetration tests. Almost all the cases studied, listed in Table 1 and the one stored in French database have been described by a detailed ground investigation campaign including dynamic and standard penetration soundings.

3.1 Calculation of bearing capacity from the in situ test

The formula used to calculate the net failure stress (bearing capacity per unit area) of a foundation subjected to a centred vertical load from the results of considered test is:

$$q_{net} = k_{test} \cdot x_c \quad (1)$$

with

q_{net} net stress,

k_{test} bearing capacity factor (i.e. k_d for DPT, k_c for CPT, etc.)

x_c equivalent resistance.

The equivalent resistance x_c is the average soil strength that can be defined by averaging resistance on a DPT or SPT or CPT, profile for a depth of 1.5 the width of the foundation.

In the case of dynamic penetration test, the average bearing factor k_d is observed to be equal to 0.225 (Amar et Morbois, 1985). The coefficients a, b and c of the curves defined by equation (2), to match the experimental data as closely as possible (Figure 5 and Table 2):

$$k_{test;\frac{B}{L}} = k_{test;0} + \left(a + b.\frac{D_e}{B}\right) \cdot \left(1 - e^{-c\cdot\frac{D_e}{B}}\right) \quad (2)$$

The dispersion of the dynamic penetrometer bearing factor k_d is similar to that observed for the bearing factor k_p defined for the pressuremeter test.

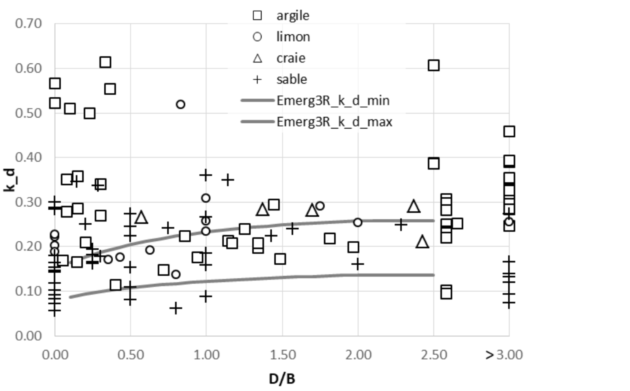

Figure 5. Effect of embedment for the different soils for the dynamic penetrometer method.

In the case of a water table at depth in sand, we consider that during a penetration test in moderately compact sand, a "liquefaction" phenomenon (thixotropy) may occur which affects the dynamic resistance of the soil (sensitivity coefficient, s_L=2). So for any test under the water table and in sand, we take:

$$q_d = q_{d\,test} \cdot s_L \quad (3)$$

Table 2. Coefficients in the expression of the bearing capacity factor k_d.

Soil category	curve	Coefficient formula (2) a	b	c	$k_{d;0}$
Clay and	L/B=∞ : Q1	0.04	0.007	1.3	0.15
loam	L/B=1: Q2	0.10	0.007	1.5	0.15
Sand and	L/B=∞ : Q3	0.04	0.009	2	0.08
gravel	L/B=1: Q4	0.03	0.04	5	0.08
Chalk	L/B=∞ : Q5	0,06	0,03	3	0,2
	L/B=1 : Q6	0,09	0,04	3	0,2

It is noted that these coefficients vary little from those adopted for the static penetrometer.

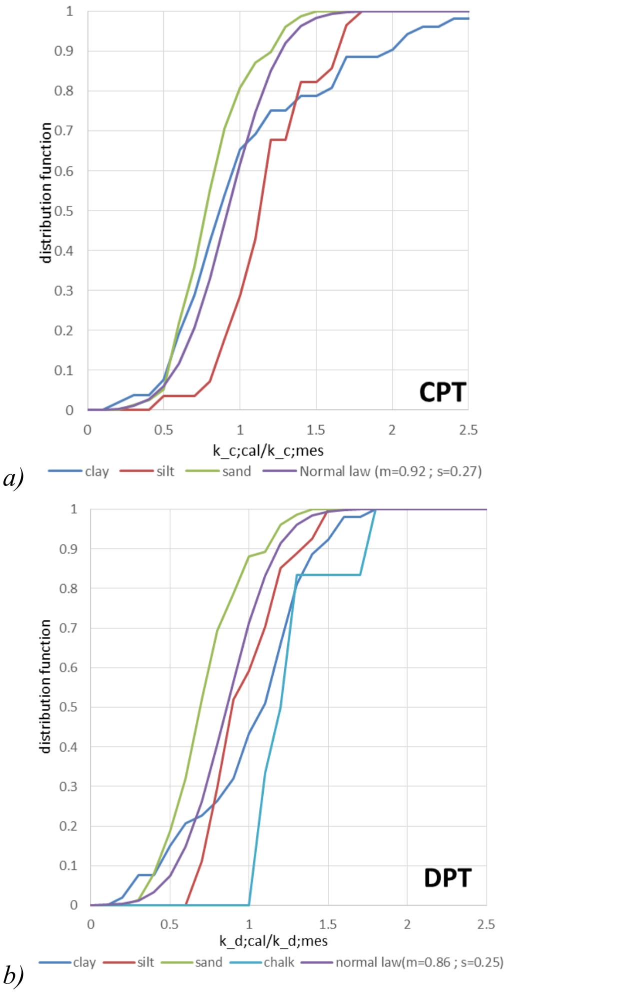

Figure 6. Distribution curves of direct design method for (a) CPT (b) DPT for different soils,

3.2 Evaluation of the method on the basis of existing data

Figure 6 compares the distribution curves of the ratios between the calculated and measured bearing capacity factors, with 147 cases collected for CPT and 98 tests for DPT. It should be noted that the calculation using the proposed relationship has a sigmoidal shape very close to that of a normal distribution for most soils. The level of safety represented by the deviation from a mean value of 1 is not observed to be totally identical in the various cases, but it remains very close to that observed on the same database for estimates based on the results of pressuremeter tests.

4 CONCLUSIONS

This paper presents the extension of the direct design method for assessing the bearing capacity of shallow foundations in situ to dynamic penetration tests. New tests have been performed to supplement the database of tests already collected in bibliography to validate the design method.

A method for estimating the bearing capacity using a dynamic penetrometer with constant and variable energy was presented and its results compared with the elements in the database, demonstrating a good quality of prediction, which should be taken into account in the French design standard NF P92-261 under revision.

ACKNOWLEDGEMENTS

The authors are grateful for the financial support provided by ANRT funding agency.

REFERENCES

Amar S., Morbois A., (1985), Contribution au dimensionnement des fondations superficielles à l'aide de l'essai au pénétromètre statique, *BLPC* 141:37-43 (in French).

Andersen, K.H. and Stenhamar, P. (1982). Static plate loading tests on overconsolidated clay. *JGED, ASCE*, 108(GT7):919-934. https://doi.org/10.1016/0148-9062(84)91235-x.

Bergdahl, U., Hult, G., & Ottosson, E. (1985). Calculation of settlements of footings in sands. In *Proc. 11th ICSMFE*. Rotterdam: Balkema. 3(8/C/5):2167-2170,

Brand, E.W., Muktabhant, C., and Taechathummarak, A. (1972). Load tests on small foundations in soft clay, *Performance of Earth and Earth-Supported Structures. ASCE*, 1(2):903-928 • https://doi.org/10.1016/0148-9062(74)92802-2.

Briaud J.L., Gibbens R. (1999) Behavior of Five Large Spread Footings in Sand. *JGGE*, 125(9): 787-796. https://doi.org/10.1061/(ASCE)1090-0241(1999)125:9(787).

Canépa Y., Garnier J. (2004) "Etudes expérimentales du comportement des fondations superficielles - Etat de l'art", *Proc. Int Symp. Fondsup 2003*, Paris, Presses de l'ENPC/LCPC, Magnan (éd), 2:155-260 (in French).

Consoli, N. C., Schnaid, F., and Milititsky, J. (1998). Interpretation of plate load tests on residual soil site. *JGGE*, 124(9):857–867. https://doi.org/10.1061/(ASCE)1090-0241(1998)124:9(857.

Ismael, N. F. (1985). Allowable pressure from loading tests on Kuwaiti soils. *CGJ*, 222:151–157.

Jardine, R.J., Lehane, B.M., Smith, P.R., Gildea, P.A. (1995). Vertical loading experiments on rigid pad foundations at Bothkennar *Géotechnique*, 45(4):573-597 https://doi.org/10.1680/geot.1995.45.4.573.

Larsson R. (1997) Investigations and Load Tests in Silty Soils. SGI, Report n° 54, 266 pages.

Larsson R. (2001) Investigations and Load Tests in Clay till, SGI, Report No 59, 169 pages.

Lehane, B., Jardine, R.J., (2003). Vertically loaded shallow foundation on soft clayey silt: A case history, *Proc. ICE, Geotech. Eng.*,.156(1):17–26.

Lehane, B.M., Doherty, J.P. & Schneider, J.A. (2008). Settlement prediction for footings on sand. *Deformation characteristics of geomaterials; Proc. 4th intern. symp.*, 1:133–150.

Lehane, B.M. (2019). CPT-based design of foundations. E.H. Davis Memorial Lecture (2017), *Australian Geomechanics*, 54(4):23-48.

Lutenegger A.-J., De Groot D.-J., (1995), Settlement of shallow foundations on granular soils. UMass, 233 pages.

Muhs, H. and Weiß, K. (1971). "Untersuchung von Grenztragfahigkeit und Setzungsverhalten flach gegründeter Einzelfundamente im ungleichförmigen nichtbindigen Boden." Berichte aus der Bauforschung, DEGEBO, Berlin, heft 69. (in German).

Shields D., Bauer G. (1975), Determination of the modulus of deformation of a sensitive clay using laboratory and in situ tests. *Proc. Spec. Conf. on In Situ Meas. Soil Prop.,* ASCE, (1):395-421.

Terzaghi K. , Peck R. (1948*) Soil Mechanics in Engineering Practice,* 1st edition, New York Wiley, 719 pages.

Viana da Fonseca A. (2001), Load tests on residual soil and settlement prediction on shallow foundation, *JGGE*, 127(10): 869-883 https://doi.org/10.1061/(ASCE)1090-0241(2001)127:10(869.