Influence factors study of cone loading test in the centrifuge

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ABSTRACT

The Cone Loading Test is a simple and easy to use test, performed with standard CPTU testing equipment and consists of stopping the penetration at a desired level and loading the cone by successive steps up to ground failure. The obtained loading curves connect the three measurements made in the electronic cone: tip resistance, sleeve friction and pore water pressure to the settlement of the cone. Physical modelling of Cone Loading Test with the LCPC centrifuge attempted to investigate the influence of the penetration or loading rate, cone geometry, embedment, soil unit weight and scale effect on the stress-strain relationship deduced from the test. The main objective of this research is to characterize the influence of these factors on the approach used to derive Young's modulus. To achieve this objective, a parametric study where the parameters were varied in their respective range, allows establishing the influence factors governing this relationship. After a short description of the test principle, this paper will summarize the testing program and enlighten the main results of Cone Loading Tests realized in geotechnical centrifuge on Fontainebleau sand.

1 INTRODUCTION

The Cone Loading Test can be carried out during a Cone Penetration Test (CPT) as a complementary, fast and economical test. The principle of the cone loading test is simple: after a dissipation test, a loading of the cone is done by successive steps or at constant very slow speed until the cone resistance of the soil is reached (Faugeras *et al*, 1983). The loading curve is then recorded, it links the pressure applied on the cone to the settlement of this cone. Figure 1 shows the test principle and the loading program which consists of carrying out a loading by stages where the pressure is held constant during 60 seconds in each stage. Several other readings are also measured, like the increase of pore pressure and the shear resistance on the friction sleeve. Examples of typical cone loading test results are described in the paper of Ali et al. (2010).

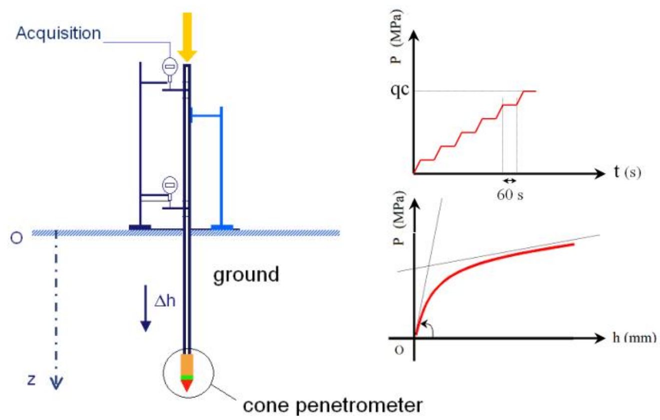


Figure 1. The principle of the cone loading test and the loading program

2 CONE LOADING TEST IN CENTRIFUGE

2.1 *Objective*

To be satisfactory, a parametric study of a cone loading test modelled in 1 g requires a large number of tests and sites. Unfortunately, experimental sites with thick layers of homogeneous sand are difficult to find. For this reason, the use of reduced scale models is a current practice in geotechnical engineering. Indeed, these models allow studying the behaviour of a ground or a structure, under complex conditions where the calculation methods do not exist or are not adapted to the studied case. Thus, the use of the centrifugal reduced models are advantageous.

2.2 *Influence factors*

In a cone loading test, several parameters have to be considered, like the cone geometry (diameter, shape), the ground state (density, nature, and homogeneity), the loading rate, the applied pressure and the loading program (step, constant rate, monotonous or cyclic). Hence, a parametric study based on testing of small scale models in centrifuge has been built to address this issue.

2.3 *LCPC Centrifuge*

The LCPC (Laboratoire Central des Ponts et Chaussées) geotechnical centrifuge has been used since 1985 for the study of scaled models. Loads are applied in flight using jacks or an on-board robot, all devices being controlled remotely from the centrifuge operator's room. The scale-reduction factor is equal to the centrifugal acceleration being applied, up to a maximum of 200 g's and the maximum model mass is 2 tons.

2.3.1 *Material: Fontainebleau sand*

Fontainebleau sand was used in these tests. It is a uniform silica sand which consists of fine and rounded particles with an average mean particle size d_{50} of 0.22 mm. The Fontainebleau sand passes through a 0.4 mm sieve and is retained on a 0.08 mm sieve. The sand has an average uniformity coefficient of 1.3. The average maximum and minimum dry densities of the sand were found to be 1706 and 1395 kg/m^3 (Table 1).

Table 1 – Maximum and minimum dry densities

γ_s (kN / m3)	$\gamma_{d\ min}$ (kN / m3)	e_{max}	$\gamma_{d\ max}$ (kN / m3)	e_{min}
26.00	13.95	0.864	17.06	0.524

2.4 *Containers*

Two series of cone loading tests have been performed with the LCPC geotechnical centrifuge (Canépa et al., 2000). Two model containers were prepared by air pluviation from a hopper to obtain densities values of γ_d = 15.95 (CT1) and 15.20 kN/m^3 (CT2) and subjected to a 50g acceleration. The characteristics of the containers are shown in table 2. The tests have been realized in medium dense sand (CT2) and dense sand (CT1).

Table 2 – Density index

Container	Weight ρ_g (t / m3)	Density γ_d (kN / m3)	Density index I_d (%)
CT1	1.626	15.95	68.8
CT2	1.550	15.20	45.1

Table 3 recapitulates the various mechanical parameters of Fontainebleau sand, obtained from shearing tests with square boxes of 6 cm on 5 cm height samples.

Table 3 – Mechanical characteristics of Fontainebleau sand

Container	Weight γ_d (kN / m3)	Friction angle (peak) φ (°)	Friction angle at rupture φ_r (°)	Dilatancy angle (φ - 30°) ψ (°)	Dilatancy angle « Rowe » ψ (°)	Drained cohesion c' (kPa)
CT1	15.95	38.3	30.7	7.6	9.2	2.6
CT2	15.20	31.6	29.2	1.6	2.8	5

3 TESTING PROGRAM

Cone penetration tests have been carried out with a 12 mm diameter (Φ) cone (Figure 2.a) without measurement of friction or pore pressures.

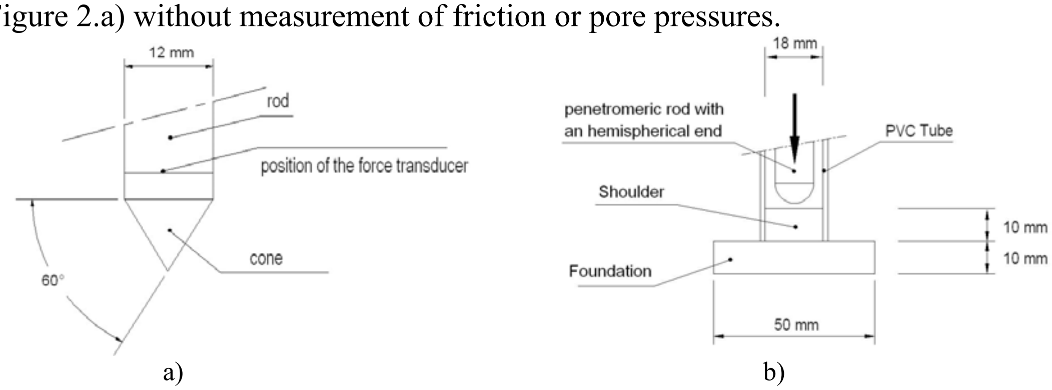
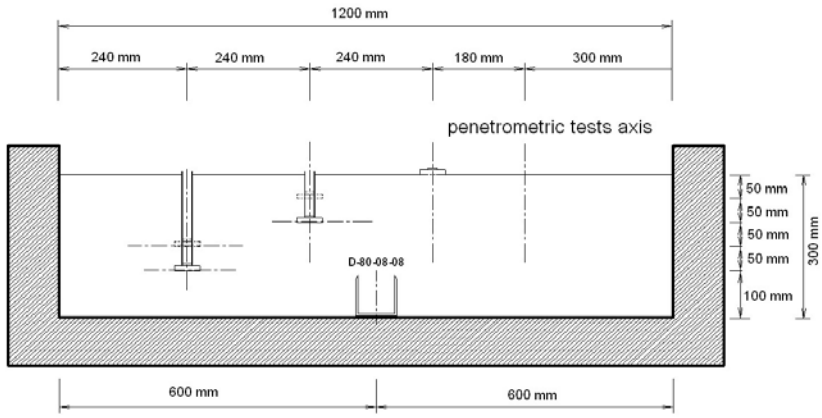
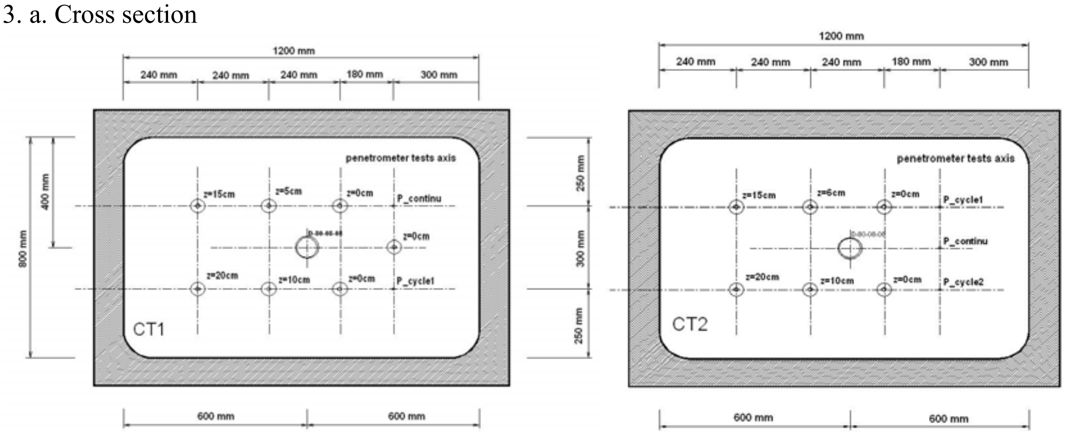


Figure 2. Description of the cone and the plate used in the tests

During these tests, unload-reload loops were carried out at four different depths (Figure 3). The modules derived from these loops are presented below and compared to measurements of modules obtained during loading tests of 50 mm diameter (B) circular plates (figure 2.b). The tests were conducted at the same penetration rate of 0.6 mm/min. The plates were embedded in the containers at the levels where the loops were realized.



3. a. Cross section



3. b. Plan view

Figure 3. Presentation of the containers used in LCPC centrifuge tests

3.1 *Procedure*

The plate loading test is carried out at a constant loading rate (2.5 mm/sec) and the unload-reload loops are also carried out at constant speed, but in this case at very slow speed (0.01 mm/sec). The tests are carried out until the maximum capacity of the penetration device (700 daN = 3500 kPa) or until a plate displacement of 5 mm (10% of its diameter). During each loading test, two or three unload-reload loops were done at Q load levels corresponding to a plate displacement of 1 mm (2%B), 2.5 mm (5%B) and 5 mm (10%B). The loops amplitude ΔQ is equal to Q/2. In the same manner, the cone penetration is done at a constant rate (2.5 mm/sec) and the unload-reload loops are also carried out at a very low constant rate (0.01 mm/sec). In each penetration test, 4 unload-reload loops were performed at depths z corresponding to the plate elevations, approximately 50 mm ($z/\Phi \approx 4$), 100 mm ($z/\Phi \approx 8$), 150 mm ($z/\Phi \approx 12$) and 200 mm ($z/\Phi \approx 16$) in the soil. The amplitude ΔQ of the loops is about

0.8Q, Q being the force from which the loop begins. Figure 4 shows a typical plate loading test and cone loading test profile.

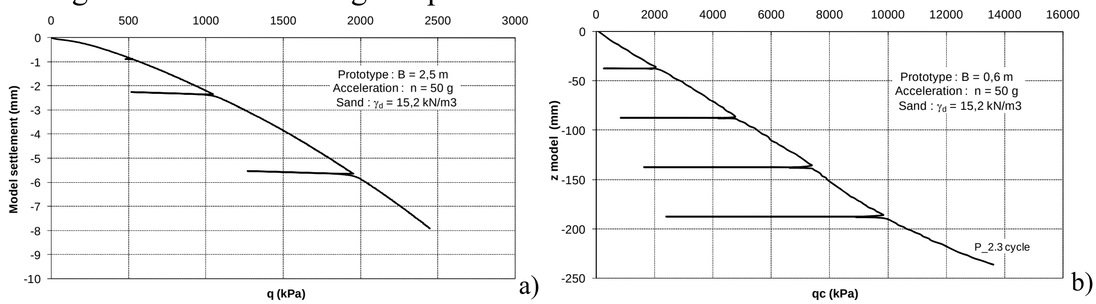


Figure 4. Typical example of (a) plate loading test and (b) cone penetration test profile with unload-reload loop (CT2)

3.2 *Measurements*

The effort transmitted to the plate (cone effort in case of penetration test) is measured by means of a transducer located at the base of the penetrometric rod (see figure 2). It is admitted that the plate's displacement (or the cone displacement) is identical to the vertical displacement of the tele-operator head by taking as measurements origin that corresponding to the first measured transducer effort lift off. The measurements periodicity is 1 second.

3.3 *Results*

3.3.1 *Unload-reload modulus*

Figure 5 shows two typical unload–reload loop curves obtained during a plate loading test and a penetration test. For each loop carried out (2 to 3 during a plate test/ 4 in each penetration test), a secant deformation modulus was calculated using the following relation:

$$E_{secant} = (\Delta q/\Delta s)_{AB} * (\pi/4) * \Phi * (1-\nu^2) \qquad (1)$$

with:

Δq : pressure amplitude

Δs : model displacement amplitude

Φ : cone base diameter (12 mm)

ν : Poisson's ratio (= 0.33)

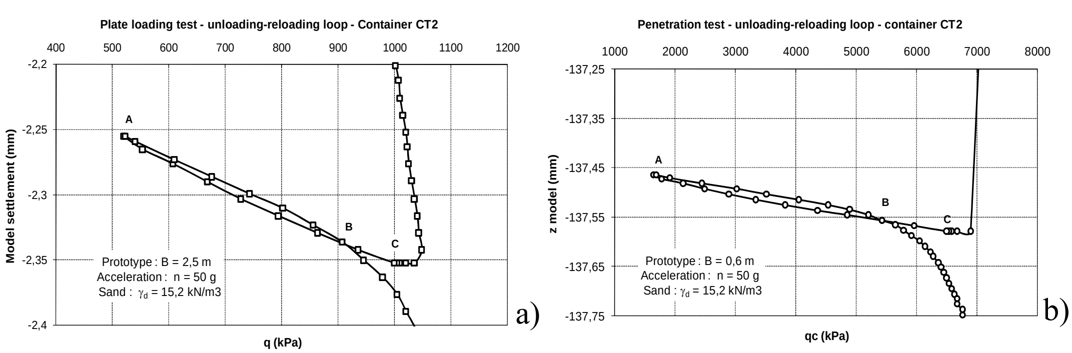


Figure 5. Typical unload-reload loops for (a) plate loading test (b) cone penetration test (CT2)

3.3.2 *Measurements repetitivity*

Figure 6.a compares the tests $F_{00\text{-}2.1}$ and $F_{00\text{-}2.2}$ carried out at surface (D= 0) in container CT2, respectively, with and without unload–reload loop. Figure 6.b compares the penetrometer profiles P-2.1 et P-2.2 et P-2.3 carried out in container CT2. As shown, the variation between the curves in each figure is very small (lower than 10 % in term of displacement for the same pressure transmitted to the ground - same cone resistance q_c in case of penetration test). The small difference between the curves proves the good reproducibility of these tests.

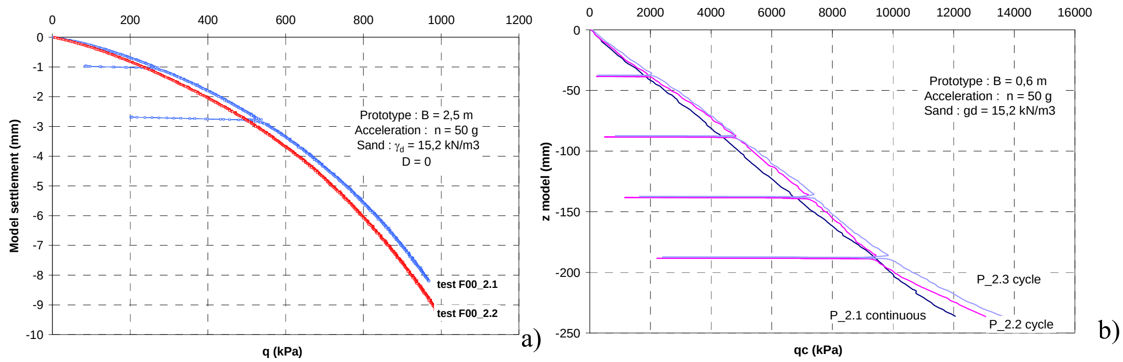


Figure 6. Measurements repetitivity

3.3.3 *Plate loading curves*

Figure 7 shows the plate loading tests carried out in container CT2. Each plate test was characterized by characteristic pressures. The curves are non dimensional (s/s_r according to q/q_r).

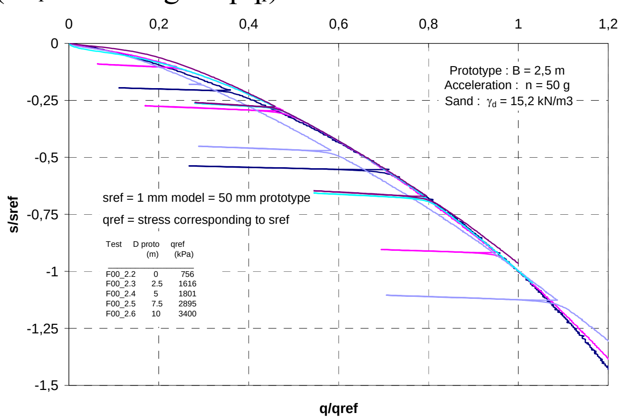


Figure 7. Plate loading tests - Container CT2 (γ_d = 15.20 kN/m^3) – non dimensional curves

Where q_r is the pressure corresponding to a displacement (s_r) equal to 10 % of B. As we can see it, the variation between the non dimensional curves is very small and a unique power function ($s/s_r = [q/q_r]^m$) can practically represent all the tests (in this case m =1.5).

3.3.4 *Deformation modulus analysis*

Figure 8 shows the evolution of the deformation modules measured according to the depth where unload-reload loop was carried out. The plotted modulus have been calculated using equation 1.

Several points can be construed from this figure:

- All matters being equal (same container, same test), the modulus increases with depth. The obtained tendency curves are shown on the figure.
- At the same depth, the modulus measured during the penetrometric tests are appreciably higher than those obtained during the plate loading tests.
- All matters being equal (same container, same depth), the modulus measured during the plate loading tests increases with applied stress level q/q_r where was used the unload – reload loop.
- The «gradient» of $\Delta E/\Delta z$ evolution seems not very sensitive to q/q_r where unload – reload loop was made. On the other hand, it is characteristic of the equipment used (plate or cone).

The cyclic modulus measured at plate loading test at the same depth and the unload-reload loops of cone loading test show a correlation factor of 2.3. This value can be assimilated to a shape factor k_r relating the use of Boussinesq assumption of equation 2 to the conical shape used during the tests.

$$\Delta h = \frac{\pi R}{2} \times P_p \times \frac{1-\nu^2}{E_{pn}} \qquad (2)$$

Where, R: cone radius; P_p: applied cone pressure; E_{pn}: cone penetrometer modulus

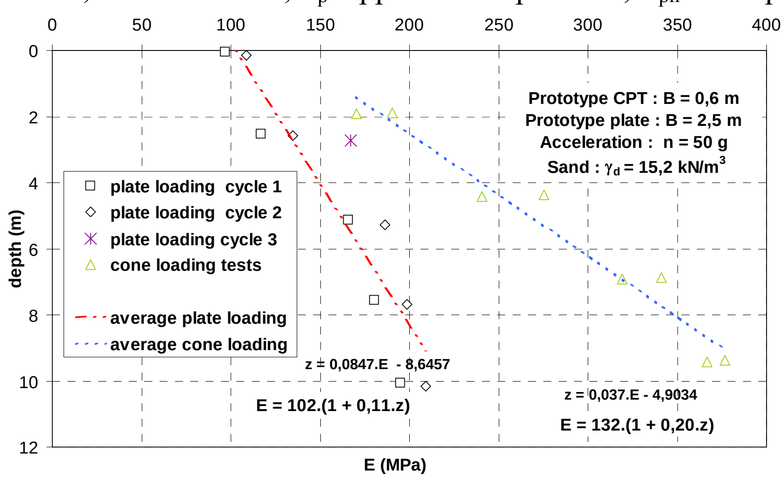


Figure 8. Secant modulus obtained by plate loading test and reloading modulus of cone loading test in centrifuge - Container CT2 (γ_d = 15.20 kN/m^3)

4 ACTUAL RESEARCH WORKS

To approach the reality of the in situ tests, a new cone penetrometer has been designed and will be able to provide measurement of cone resistance and side friction on a sleeve. The geometry and dimensions of the cone penetrometer were defined, according to the standard EN/ISO 22476-1, the ratio (length of the friction sleeve/diameter) is equal to 3.75, and as the point and the sleeve have the same diameter of 20 mm, the sleeve thus have a 75 mm length (CEN/ISO, 2005).

The objective of this new equipment is to widen the parametric study of cone loading tests in centrifuge. The program of the new tests is being prepared; it is a more detailed study of the influence of several parameters on the test results, in particular, the influence of the penetration rate, various cone and plate geometries, as well as the effect of the soil density.

5 CONCLUSIONS

This paper describes the insertion of a cone penetrometer (Φ = 12 mm) carried out in a centrifuge (N = 50 G) in two Fontainebleau sand masses of various densities (γ_d = 15.95 kN/m^3 and γ_d = 15.20 kN/m^3). During these tests, unload – reload loops were applied at various depth levels, and deformation moduli were calculated from each test. This paper clearly shows the correlation between results of cone loading tests and those obtained from plate loading tests in centrifuge. It is evident that these conclusions are specific to the materials and equipment. Further research is needed in this direction (comprehension of the cone resistance, complete analysis of the loading curves) in order to assess soil deformation properties and the design of spread footings using in situ penetrometer tests.

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