Use of mini CPT to evaluate degree of compaction in fine-grained soils

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ABSTRACT: An innovative procedure for assessing the degree of compaction of earth works of fine grained soils has been developed and evaluated. The procedure is described and example results presented. The procedure is based on mini-CPT results performed on laboratory compacted samples. The method was evaluated at a river embankment constructed using compacted fine-grained soils. Undisturbed sampling was used to check the in situ dry density. The methodology was positively evaluated with promising results.

1 INTRODUCTION

An innovative procedure for assessing the degree of compaction of earth works of fine-grained soils has been developed and evaluated. The proposed method is mainly based on the following hypotheses:

- the CPT tip resistance (q_c) is not affected by the tip diameter, therefore we expect to measure the same q_c (in the same soil under the same conditions) using a standard cone having a diameter of 35.7 mm and a mini – penetrometer with a diameter of 8 mm;
- the tip resistance measured in situ using a standard cone [$q_{c(standard)}$] and that measured in a mini – Calibration Chamber (mini – CC) using a mini-penetrometer [$q_{c(mini)}$] under the condition of no lateral strain are the same for the same soil, with the same density and vertical effective stress;

If the above indicated assumptions are true, it is possible to measure $q_{c(mini)}$ in the laboratory using specimens reconstituted at the prescribed density in a Proctor – mold and consolidated at different vertical pressures. We expect that $q_{c(standard)}$ measured in situ is the same as $q_{c(mini)}$ for the same soil with the same density and vertical effective stress. Therefore, we can (a – priori) establish which is the expected CPT q_c corresponding to a prescribed density.

The assumptions have been experimentally verified and the proposed method has been applied in a real case. The construction material was classified as A4 to A6 according to AASHTO M 145 (1991).

The practical application of the method gave a further verification of the correctness of the previously indicated hypotheses. In fact, "undisturbed" samples were retrieved with different methods at the river embankment, giving a direct evaluation of the soil density in situ.

A similar procedure is described by XP P 94-063 (1997) and XP P 94-105 (2000). This procedure is applied to coarse grained soils and requires the construction of a trial embankment and the performance of dynamic penetration tests. This procedure is applied to the control of the degree of compaction for trenches (Setra – Lcpc 1994, 2007).

It is worthwhile to remark that there are few specific studies concerning the performance criteria of river embankments. As a consequence, in most cases the same design prescriptions are adopted as for road embankments or for earth-dams, which control type of material and degree of compaction.

2 MINI CALIBRATION CHAMBER AND MINI CONE

The mini calibration chamber equipment (Figure 1) consists of two end platens connected by three tie rods, an air piston fixed onto the lower end platen and a Proctor - mold, which represents the mini – CC. The mold contains the test soil compacted to the desired density and is located between the air piston and the upper end platen. The air piston can apply a vertical pressure to the soil in the Proctor – mold through a rigid platen. The contrast is given by the upper end platen. Additional information on the equipment is available in Carelli (2009) and Vuodo (2009).

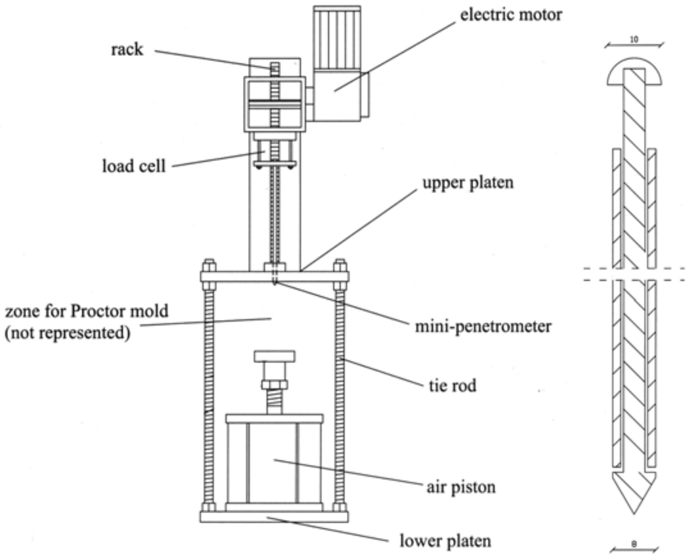

Figure 1. Scheme of mini calibration chamber and mini cone.

3 EXPERIMENTAL ASSESSMENT OF THE WORKING HYPOTHESES

Two different types of experimental activities have been run to verify the working hypotheses. The first step was to verify that the $q_{c(mini)}$ is equal to $q_{c(standard)}$ under the same site conditions. To this purpose in situ penetration tests using a standard cone and a mini cone in the same site at close distances have been carried out. In a second step the hypothesis that the effects of the mini – chamber sizes can be considered negligible has been verified. For this purpose some tests in the mini – CC with the mini – penetrometer using Ticino sand (TS) were performed. There is a huge literature concerning the cone penetration tests (CPT) run in CC on TS samples to which refer the results of tests carried out in the present research (e.g. Baldi et al. 1986, Jamiolkowski et al. 2000, 2001).

3.1 *In situ assessment*

Four tests with a standard cone and four tests with a mini – cone were run in Calendasco (PC – Italy) on dry sandy silts. The tests were performed at close distance from each other (about 1m). The upper and lower envelopes obtained with the two different cones are shown in Figure 2. There is very little discrepancy between the results obtained with the two different cones.

3.2 *Laboratory assessment*

Penetration tests, using the mini – cone, were run on TS samples reconstituted to a given relative density (about 50 %) in the mini – CC and consolidated under BC3 conditions (no lateral strain) under a given vertical pressure (100 ÷ 400 kPa). More specifically the so – called TS4 (γ_{dmin} = 13.91 kN/m^3; γ_{dmax} = 17.00 kN/m^3) was used for the tests. For these tests the ratio between the mini - CC diameter and the cone diameter (D_c/d_c) is equal to 19.5.

The results were compared to those obtained in a large CC using the standard cone under BC1 conditions (constant vertical and horizontal stresses). For these tests Dc/dc = 33.6.

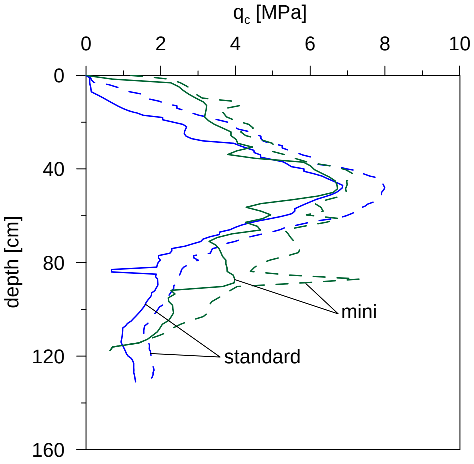

Figure 2. Comparison between standard CPT and mini cone at Calendasco site of dry sandy silt

Figure 3 shows typical examples of mini cone tip resistance with depth in the mini - CC. In one case the tip resistance attains a constant value, in the other case the tip resistance is continuously increasing. According to a well-established practice, the tip resistance at mid – height of CC was selected as reference value (Garizio 1997).

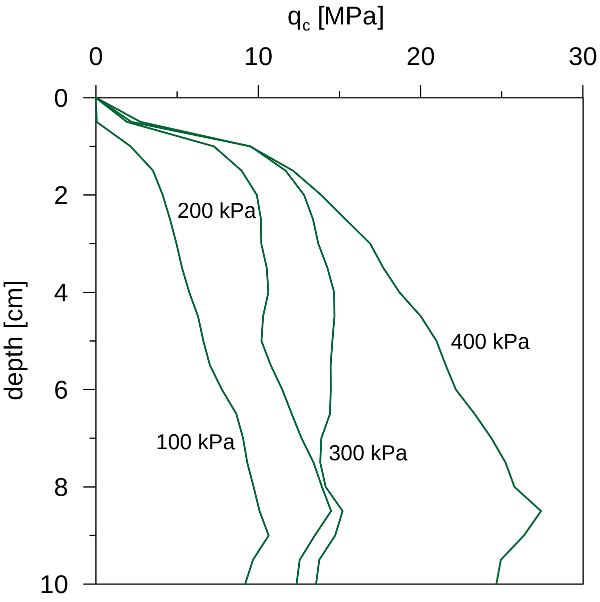

Figure 3. Mini cone measurements in mini-CC on Ticino sand at 50% relative density

The correlations given for the TS by Baldi et al. (1986) and Jamiolkowski et al. (1988) were used for comparison. More specifically the tip resistance in the large CC with a standard cone was determined according to the following Equation 1:

$$q_c = C_0\,(\sigma'_{v0})^{C1} e^{(Dr\ C2)} \qquad (1)$$

where C_0, C_1 and C_2 are empirical coefficients, respectively equal to 172, 0.51 e 2.73. The term σ'_{v0} is the applied vertical pressure and Dr is the relative density of the sample in the mini - CC. The comparison is shown in Figure 4.

There are several reasons to suppose that $q_{c(mini)}$ in the mini – CC must be different than $q_{c(CC)}$ in the large CC. More specifically:

- The Dc/dc ratio is different. For this reason the $q_{c(mini)}$ is expected lower than $q_{c(CC)}$. Several relationships have been suggested to take into account this aspect of phenomenon (Mayne & Kulhawy, 1991, Tanizawa, 1992, Garizio, 1997), but without a shared point of view;
- Tests performed with the mini – penetrometer in the mini – CC were run under BC3 condition. On the contrary the tests in the large CC were run under BC1 condition which is more representative of the conditions in an embankment. For this reason we also expect $q_{c(mini)} > q_{c(CC)}$. Unfortunately there are not enough experimental evidences to quantify this effect;

- The large CC has flexible boundaries (i.e. about nil fiction). On the contrary the mini – CC has rigid boundaries and therefore very high friction. For this reason we expect that $q_{c(mini)} < q_{c(CC)}$.

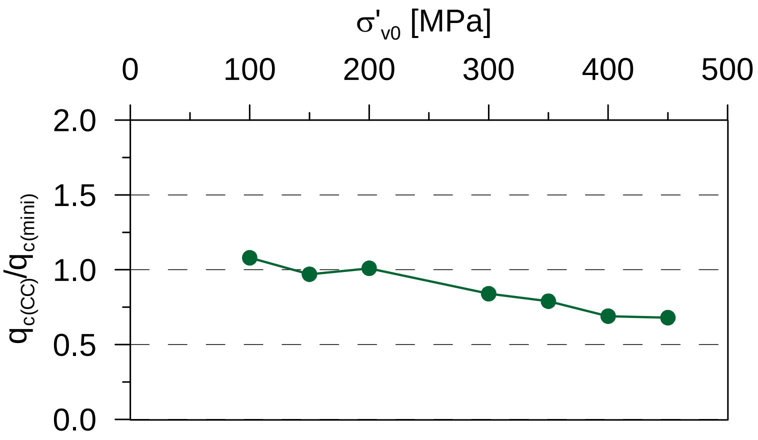

Figure 4. Comparison of results obtained with mini cone in mini-CC with equivalent standard cone in large CC using Equation 1

In the light of the above considerations, it is possible to assume that for the selected relative density there is a sort of effect compensation of the recalled phenomena within the pressure interval 100 – 300 kPa, so that $q_{c(CC)}/q_{c(mini)}$ is about equal to 1. It is worthwhile to remark that the indicated interval contains the stress level involved in the real case discussed in the next paragraph.

4 APPLICATION OF THE METHOD TO A REAL CASE

4.1 *Design prescriptions*

The main prescriptions for the contractor can be summarised as follows:

- a material classified as A4 to A6, according to AASHTO M 145 (1991), should be used for the embankment construction;
- lift of 30 cm of compacted material should be realised;
- minimum degree of compaction should correspond to a dry volume weight not less than 90% of the optimum density, without any specification of which optimum should be considered (Standard Proctor or Modified Proctor).

It is worthwhile to point out that, as a consequence of an especially wet season with intense and continuous raining, when the embankment construction was initiated the water table was at the base of the embankment. There was no specific prescription in the contract, which considered this adverse condition and possible countermeasures.

4.2 *Soil type and classification*

The following tests were performed on several samples of the construction material in order to control its quality:

- Standard Proctor (γ_{opt} = 15.7 kN/m^3; w_{opt} = 12.3 %)
- Modified Proctor (γ_{opt} = 20.6 kN/m^3; w_{opt} = 9.6 %)
- Grain size distribution (% sand = 40÷60; %silt = 30÷50; %clay = 10÷20)
- Index properties (LL ~ 30%; PI ~ 9 %)

4.3 *Control of the degree of compaction*

The degree of compaction was evaluated in the following way:

- Mini cone tests were performed in the lab on specimens reconstituted at two different densities corresponding to 80 and 90% of the optimum (Modified Proctor). For each density several specimens were reconsolidated at different vertical pressures. For each density data have been interpolated using the equation $q_c = C_0 (z)^{C1}$;
- CPT's with the standard cone were performed in situ at three different locations in the embankment. For this purpose we used a TG63-200 static/dynamic penetrometer by Pagani Geotechnical Equipment (Pagani 2009);
- Undisturbed (or partially disturbed) samples were retrieved at the same locations of the in situ CPT's. More specifically three very shallow block samples were retrieved. In addition, at two locations a specially devised sampler (AF shallow coring system) was used (Principe et al. 1997, 2007). The first sample extended down to a depth of 340 cm. The second only reached a depth of 90 cm, because of a failure of the equipment.

The AF shallow coring system is a very light equipment (handly transportable) which enables one to obtain up to 10 m long, continuous and partially disturbed micro-cores. For the case under consideration 38 mm in diameter cores were retrieved. The penetration of the equipment and elevation of the top of the sample were frequently monitored in order to account for a sample compaction during coring operations. The core diameter after extraction was also measured.

Figure 5 shows the in situ CPT profile (at a given location), interpolation curves of the laboratory mini cone tip resistance, dry unit weight from "undisturbed" samples as a percentage of the optimum density (Modified Proctor) and end of the embankment.

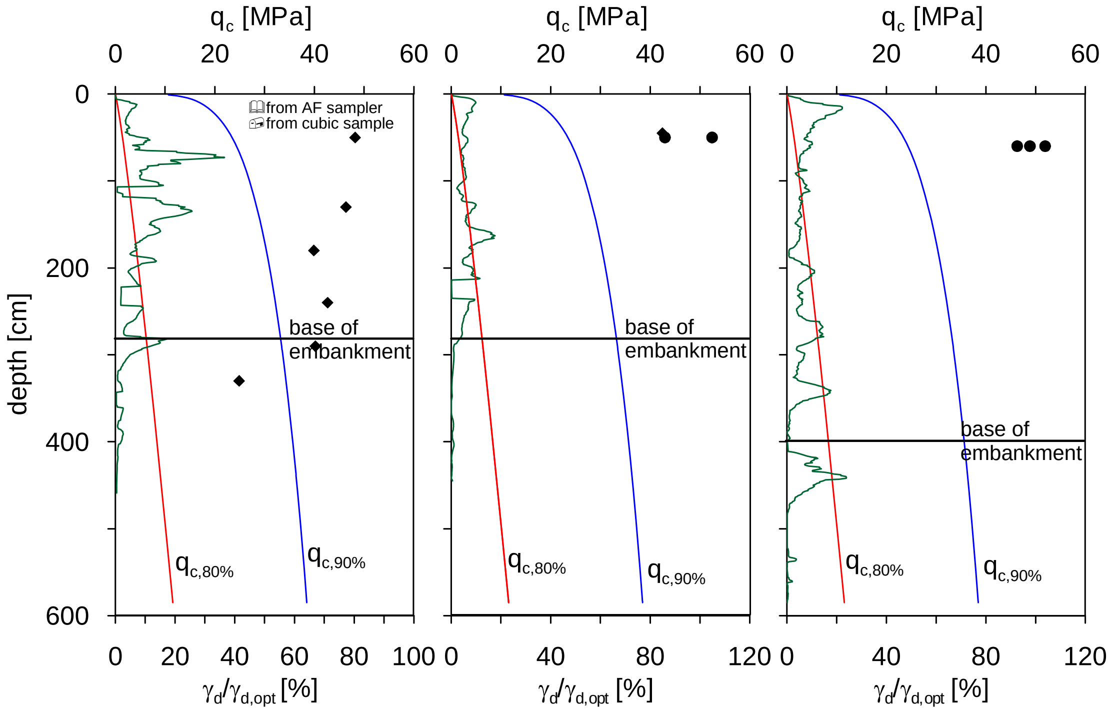

Figure 5. Results of in situ tests. Dots are referred to lower axis.

It is possible to observe that the measured laboratory and in situ values of tip resistances are consistent each other considering the in situ determined dry density.

The very low value of tip resistance at the bottom of the embankment is also quite evident, as expected as a consequence of the very high water content of the first layer, which probably was higher than 30 cm.

5 CONCLUSIONS

The proposed method was successfully applied as a quick control tool of the density of a river embankment.

The authors believe that further research is necessary to clearly define the design criteria of river embankments. Probably the construction details and type of soil are more relevant than the compaction degree.

Anyway, the proposed method seems applicable to any earthwork using fine soils.

ACKNOWLEDGEMENT

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REFERENCE

AASHTO M 145 1991. *Standard Specification for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes*

Baldi, G., Bellotti, R., Ghionna, V., Jamiolkowski, M. & Pasqualini, E. 1986. Interpretation of CPT's and CPTU's. 2nd Part: Drained Penetration. *Proceeding 4th International Geotechnical Seminar*, Singapore, pp.143-156

Carelli I. 2009. *Metodi di controllo tradizionali ed innovativi di costruzioni in materiali sciolti*. B. Thesis - Department of Civil Engineering - University of Pisa. In Italian.

Fioravante V, Jamiolkowski M., Tanizawa F. e Tatsuoka F. 1991. Results of CPT's in Toyoura Quartz Sand. Proceedings of the First International Symposium on Calibration Chamber Testing – *ISOCCT1, Postdam, New York*/ 28-29 June 1991 pp 135-145. Elsevier New York.

Garizio G.M. 1997. *Determinazione dei parametri geotecnici e in particolare di K0 da prove penetrometriche* M.Sc. Department of Structural Engineering, Politecnico di Torino. In Italian.

Jamiolkowski M., Ghionna V.N., Lancellotta R. & Pasqualini E. 1988. New correlations of penetration tests for design practice. *Proc., Penetration Testing 1988, ISOPT 1*, Orlando, Florida, J. De Ruiter ed., Vol. 1 pp: 263-296

Jamiolkowski M., Lo Presti D.C.F. & Garizio G.M. 2000. Correlation between Relative Density and Cone Resistance for Silica Sands. *75th Anniversary of Karl Terzagni's ERDBAU*

Jamiolkowski M., Lo Presti D.C.F. & Manassero M. 2001. Evaluation of Relative Density and Shear Strength of Sands from CPT and DMT, *Invited Lecture Ladd Symposium*, GSP No. 119, ASCE, pp. 201-238.

Maine, P. W., Kulhawy, F. H. 1991. Calibration chamber database and boundary effects correction for CPT data. *In Calibration chamber Testing*. New York: Elsevier, pp. 257-264.

Pagani 2009. http://www.pagani-geotechnical.com

Principe C. Malfatti A., Rosi M., Ambrosio M. Fagioli M.T. 1997. Metodologia innovativa di carotaggio microstratigrafico: esempio di applicazione alla tefrostratigrafia di prodotti vulcanici distali. *Geologia Tecnica Ambientale* Vol 39, 4/97. In Italian.

Principe C., Malfatti A.,. Ambrosio M., Fagioli M.T., Rosi M.,. Ceccanti B., Arrighi S., Innamorati D. (2007) Finding distal Vesuvius tephra at the borders of Lago Grande di Monticchio, in *AF SHALLOW CORING SYSTEM micro-cores. Atti Soc. tosc. Sci. nat., Mem., Serie A*, 112 (2007). pagg. 189-197, figg. 4, tabb. 4

Setra – Lcpc. 1994. *Remblelayage des tranchées et réfection des chaussées – Guide Technique*. Setra/LCPC, réf. D9441

Setra – Lcpc. 2007. *Remblelayage des tranchées et réfection des chaussées – Compléments*. Setra/LCPC, no. 117

Tanizawa F. 1992. Correlations between cone resistance and mechanical properties of uniform clean sand, *Internal Report ENEL – CRIS,* Milan.

Vuodo C. 2009. *Uso delle prove CPT per il controllo della qualità dei rilevati* B. Thesis - Department of Civil Engineering - University of Pisa. In Italian.

XP P 94-063. 1997. *Controle de la qualité du compactage-methode au penetrometre dynamique a energie constante*. AFNOR

XP P 94-105. 2000. *Controle de la qualité du compactage-methode au penetrometre dynamique a energie variable*. AFNOR