Comparative Study of Foundation Systems from Menard Pressure Meter and Cone Penetration Results

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ABSTRACT

Geotechnical engineering relies, in most of the cases, on empirical observations and experience. One of the main reasons for relying upon observed results is that there are practical restrictions involved in extracting quality soil samples and performing laboratory testing. This paper presents a comparative study of a foundation system obtained from geotechnical investigations carried out by HYDROSOL at the power plant in Sousse-Tunisia. A synthesis of previous research is presented and then the present study is detailed based on the results of Menard pressure meter test (MPT) and static cone penetrometer test (CPT) under the water tank. In this project, two foundation system modes have been proposed; Continuous Flight Auger (CFA) pile system proposed by the company and driven pile system proposed by "STEG" (Tunisian Company of Electricity and Gaz). Based on the results of the geotechnical investigations, we chose a foundation system that corresponds to a series of CFA piles to overcome a reinforced concrete slab.

KEYWORDS: Foundation system, Menard pressure meter test, Cone penetrometer test, Continuous flight auger.

INTRODUCTION

The establishment of any civil engineering project requires a thorough knowledge of foundation soil. Therefore, it is necessary to determine the nature of layers to a depth sufficient to the right of the area to build and the characteristics of the land, either in the laboratory on undisturbed samples at random or *in situ*. This geotechnical study of the land allows perfect definition of the type of foundation that will ensure the overall stability of the structure and prevent differential settlement that can create the ruin of construction.

Cone Penetration Test (CPT) and Menard Pressure Meter Test (MPT) have been extensively used to measure *in situ* soil properties and for the design of foundations (Begemann, 1963; Van, 1957; Dinesh et al., 1963; Ménard, 1963). These tests are a useful and economical way for obtaining reliable *in situ* properties of soils. The pressure meter test provides the measurement of *in situ* stress-strain response of soils. From this test, the design foundations can be performed using pressure meter rules that require a limit pressure and a pressure meter modulus. These are derived from the pressure meter curve or deduced from existing correlations with undrained cohesion and internal angle friction (Ménard, 1957; Amar et al., 1972). In particular, these parameters are used to evaluate the bearing capacity of soil foundations and the expected settlements. But, they can also help identify usual soil parameters required by simple constitutive models for soils in numerical calculations.

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The MPT, mostly used, also gives an estimate of the settlements (Gambin, 1963; Frank et al., 1982). The CPT itself is simpler to perform and multiplies the survey points during a geotechnical site investigation. The conduct of a reconnaissance campaign is always progressive and never fixed in advance with rigor; indeed, the processes depend on land and the test current problems met are often common.

Through this article, we are interested in the project of the construction of the power plant in Sousse which lies close to the Mediterranean Sea over a soil with low mechanical characteristics. Indeed, it is a very important example of the study of foundations due to the nature of the loose sand layer and silty sand layer. In addition, the loads transmitted through the structure are very important. This article then presents an analysis of the results of MPT and CPT and a comparative study of the foundation systems (driven piles, CFA piles and bored piles).

SITE PRESENTATION

The thermal power plant is located at Sousse, Tunisia (Figure 1). Location coordinates are: latitude= 35.7848, longitude= 10.6791. This infrastructure is of the type gas power plant with a design capacity of 306 MW. The project aims at satisfying the increasing demand for electric power and energy in Tunisia, by increasing the installed generation capacity in central Tunisia by about 400 MW. This will be achieved through adding a new single-shaft combined cycle generating module to the existing power station at Sousse.

In Situ Tests

To characterize the soil of the power plant, some tests were carried out between March and June 2013. The soil identification is based on the data in stratigraphic sections and the results of *in situ* tests. The values of geotechnical parameters have been drawn from MPT, CPT and a cup made from a core drilling.

Figure (1): Location of the power plant

Menard Pressure Meter Test

A pressure meter is basically a cylindrical probe with an expandable flexible membrane. A uniform hydraulic or gas pressure can be applied to the walls of the test pocket through the membrane to get the ground response curve; *viz*., applied pressure *versus* expansion of the membrane (Figure 2). The ground response curve can be interpreted to obtain fundamental soil properties and design parameters, such as strength, stiffness and *in situ* horizontal stress.

MPT was performed in accordance with the requirements of NF P 94-110-1 (NF P94-110-1, 2000). The results are shown in Figure 3.

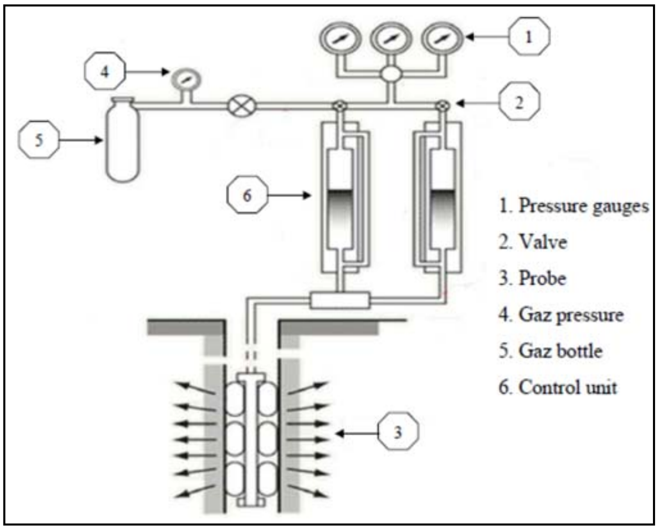

Figure (2): Schematic representation of MPT (Weltman et al., 1983)

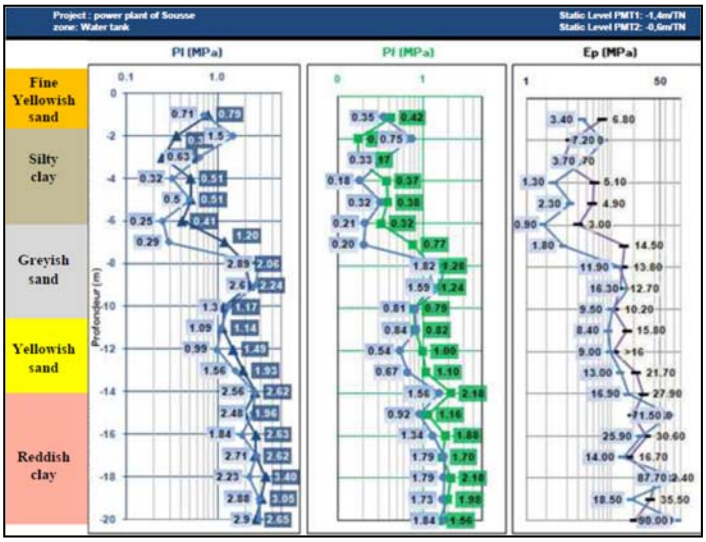

Figure (3): Pressure meter test results

Cone Penetration Test

The CPT is an *in situ* testing method used to determine the geotechnical engineering properties of soils and delineate soil stratigraphy. The test method consists of pushing an instrumented cone tip first into the ground at a controlled rate (Figure 4).

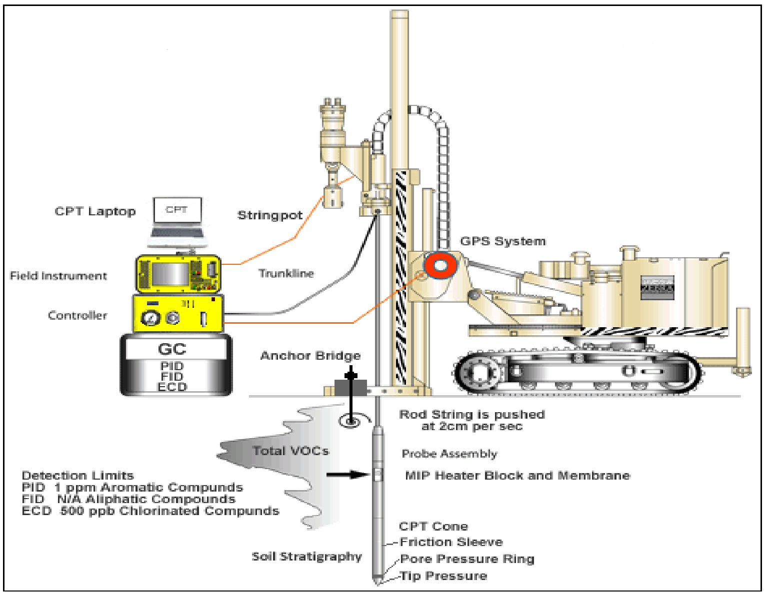

Figure (4): Schematic representation of CPT

The resolution of the CPT in delineating stratigraphic layers is related to the size of the cone tip, with typical cone tips having a cross-sectional area of either 10 or 15 cm².

The CPT was performed in accordance with the requirements of NF P 94-113 (NF P94-113, 1996). The results are shown in Figure 5.

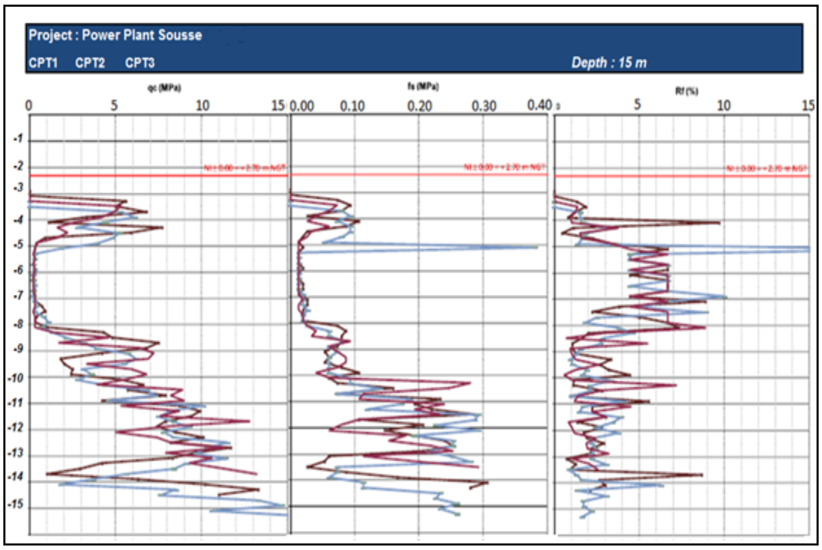

Figure (5): CPT results

Standard Penetration Test

The Standard Penetration Test (SPT) is an *in situ* dynamic penetration test designed to provide information on the geotechnical engineering properties of soil. The main purpose of the test is to provide an indication of the relative density of granular deposits, such as sands and gravels, from which it is virtually impossible to obtain undisturbed samples. The SPT core sampling was performed in accordance with the requirements of NF P 94-116 (NF P94-116, 1991). The water table level varies between 0.6 m and 1.5 m. The results are shown in Figure 6.

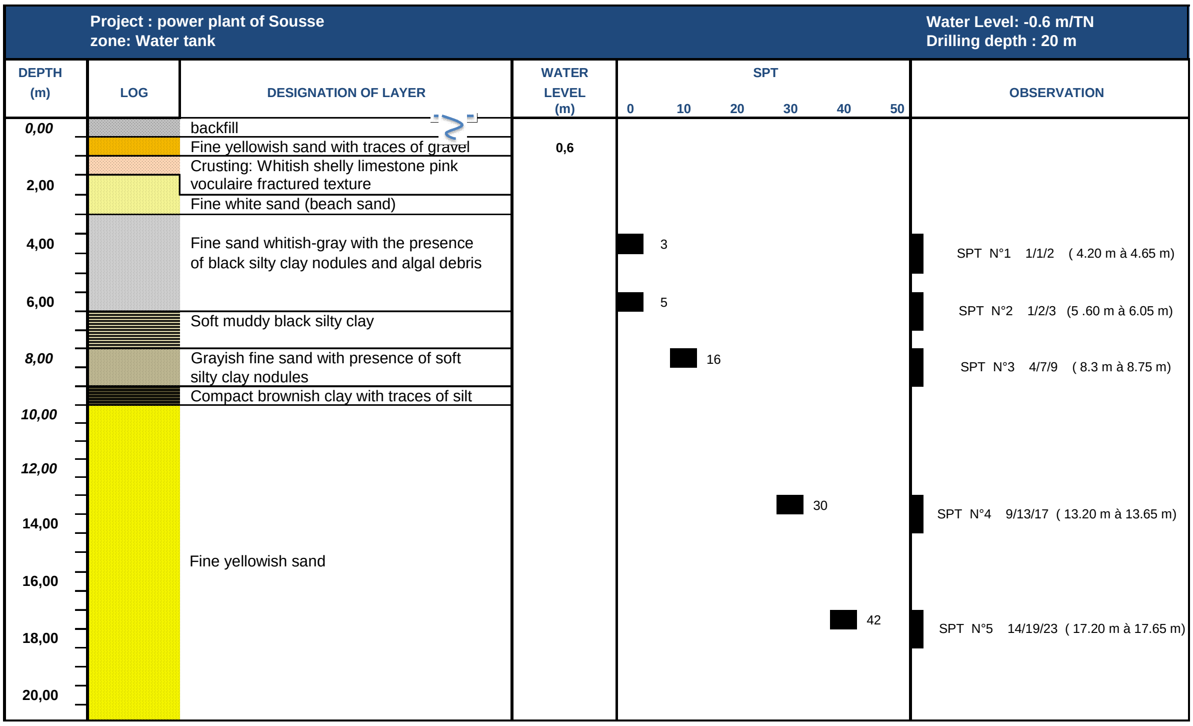

Figure (6): SPT core sampler results

STUDY OF FOUNDATION SYSTEM

Basis of Calculation

The load values are the results of design calculations which provide the loads transmitted from the tank to the foundation. Figure 7 shows the calculation models adopted for the foundation.

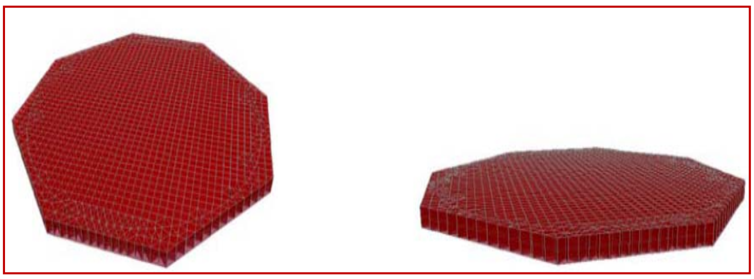

Figure (7): 3D views of the foundation of the water tank

Calculation According to MPT Results

The calculations were carried out according to standards (Fascicule n° 62, titre V., 1993). The ultimate limit of peak load is given by Equation 1:

$$Q_p = A.kp.ple^* \quad (1)$$

A: tip section; kp: tip bearing factor; ple *: net equivalent limit pressure.

The lateral friction limit load is given by Equation 2:

$$Q_s = P\int_0^h q_s(z)\,dz \quad (2)$$

P: perimeter of the pile; q_s (z): limit unit skin friction at the height z; h: height which actually carries lateral friction.

The tip bearing factor kp is found from charts based on a range of soil classes and depends on the nature of soil, its density and the installation process. The limit unit shaft friction qs is given by empirical charts of limit pressure plotted against the nature and density of the soil, the method of installation of the pile and the nature of the pile shaft (Bustamante et al., 2009; Bustamante et al., 1981).

The calculation was performed on a single pile continuous flight auger (CFA) type; anchor pile is 14 m with a selected pile diameter of 800 mm. The results are shown in Figure 8.

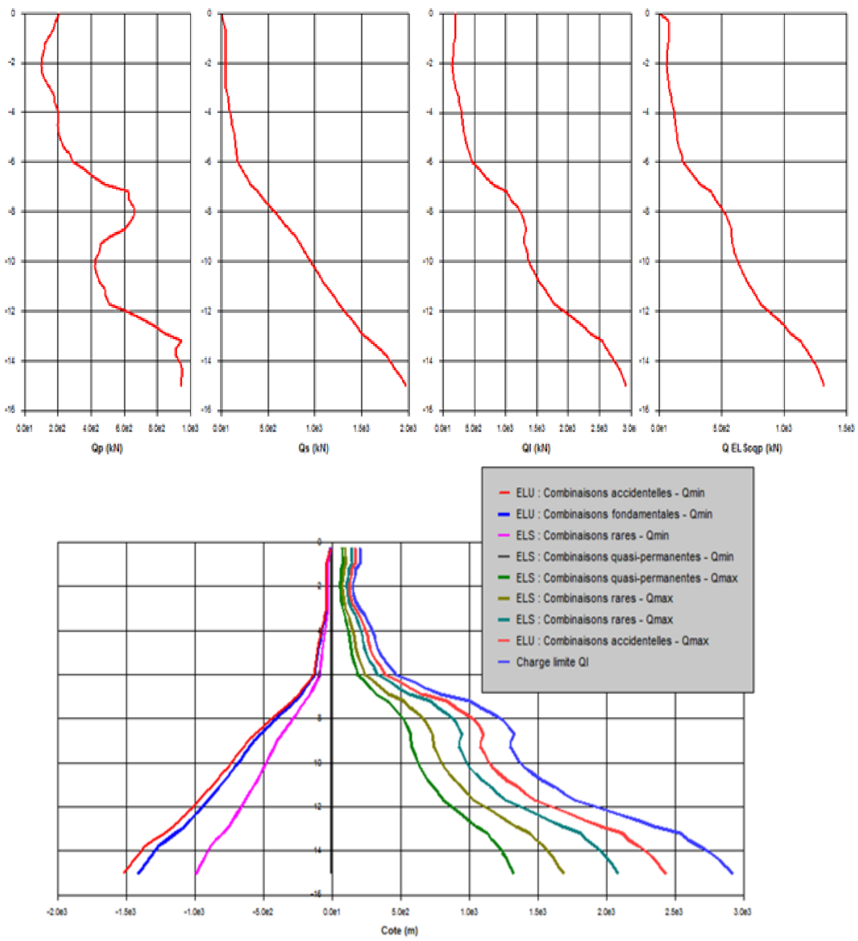

Figure (8): Load on the pile according to MPT

Table 1. Maximum actions applied on the tank

	Compression	**Traction**
Max Actions [kN]	35000	-

Calculation According to CPT Results

The calculations were carried out according to standards (Fascicule n° 62, titre V., 1993). The peak load limit is given by Equation 3:

$$Q_p = A.k_c.q_{ce} \quad (3)$$

A: tip section; q_{ce}: equivalent peak static strength from CPT; k_c: tip bearing factor.

The lateral friction limit load is given by Equation 4:

$$Q_s = P\int_0^h q_s(z)\,dz \quad (4)$$

P: perimeter of the pile; h: height which actually carries lateral friction; q_s (z): unit side friction limit at the height z determined by Equation 5:

$$q_s(z) = \min\left\{\frac{q_c(z)}{\beta}; q_{s\max}\right\} \quad (5)$$

The calculation was performed on a single pile continuous flight auger (CFA) type; anchor pile is 14 m with a selected pile diameter of 800 mm. The results are shown in Figure 9.

According to the results shown in Figures 8 and 9 of the tests performed on a single continuous flight auger (CFA) pile, the values of admissible loads were determined. Table 2 gives the values of admissible loads using MPT and CPT.

Comparative Study of Foundation Systems

The development of this study was based on the results of the MPT, because it is the most used method for the design of foundations of structures. The major advantage of this test is that it reflects best the actual behavior of the soil. A comparison of bearing piles of three types of foundation systems was performed: bored piles, CFA piles and driven piles (Figure 10). For different types of piles, the anchorage length is the same which is of the order of 14 m. The diameter of CFA piles and bored piles is equal to 800 mm. For the driven pile type, the selected section is square of 40 cm.

Table 3 gives the values of admissible load bearing capacity for the different types of piles. We note that the bearing capacity of the CFA pile is slightly higher than in the other bearing piles, while the driven pile has the lowest bearing capacity.

Table 2. Admissible loads using MPT and CPT

Admissible Loads	**MPT**	**CPT**
QEIScqp [kN]	1323	1374

Table 3. Load bearing capacity for the different types of piles

Bearing Capacity	**CFA Pile**	**Driven Pile**	**Bored Pile**
QEIScqp [kN]	1323	1110	1285

Choice of Foundation System

In this project, two foundation system modes have been proposed; CFA pile system proposed by the company and driven pile system proposed by "STEG". At the end, the choice of CFA piles is retained.

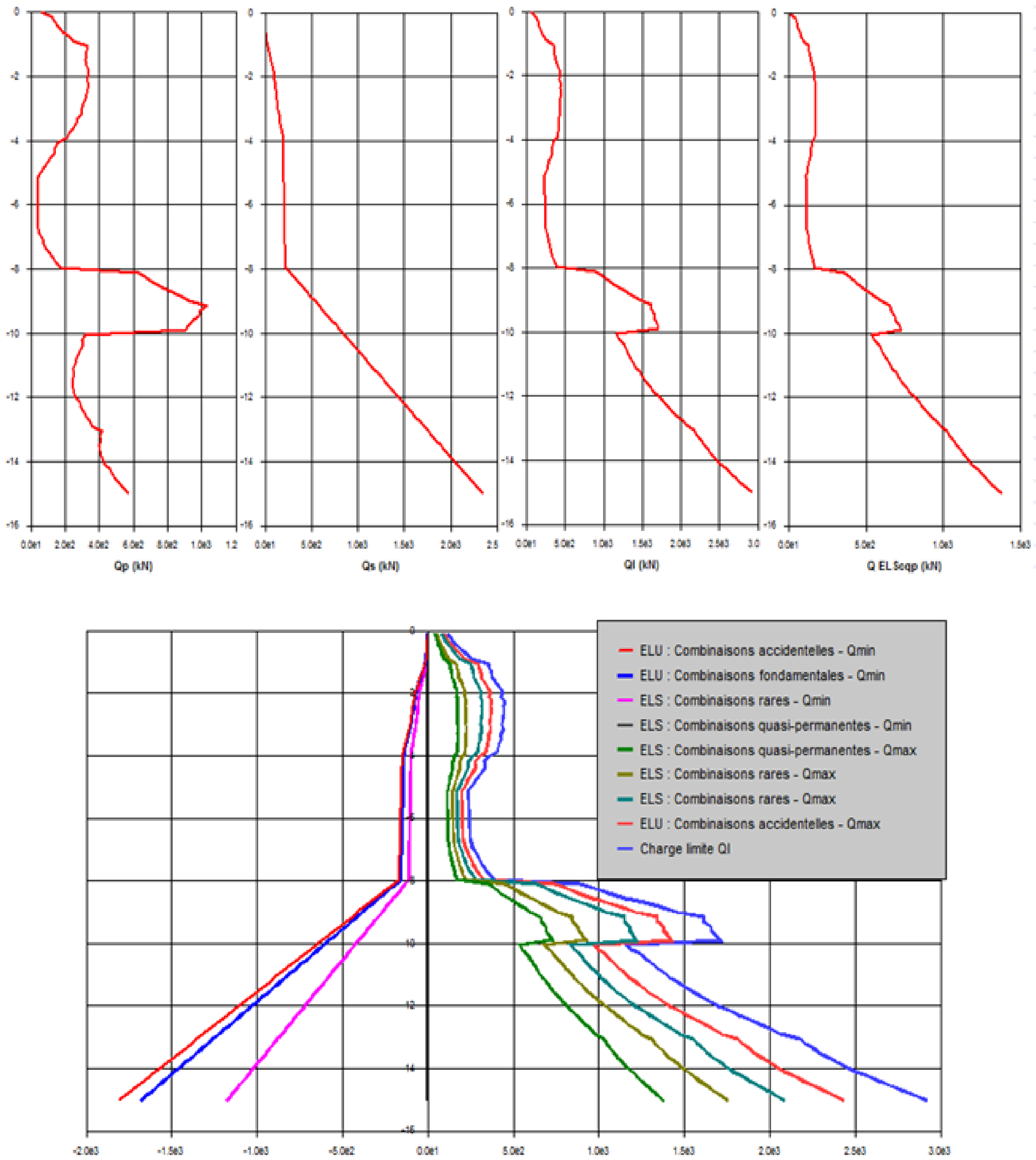

Figure (9): Load on the pile according to CPT

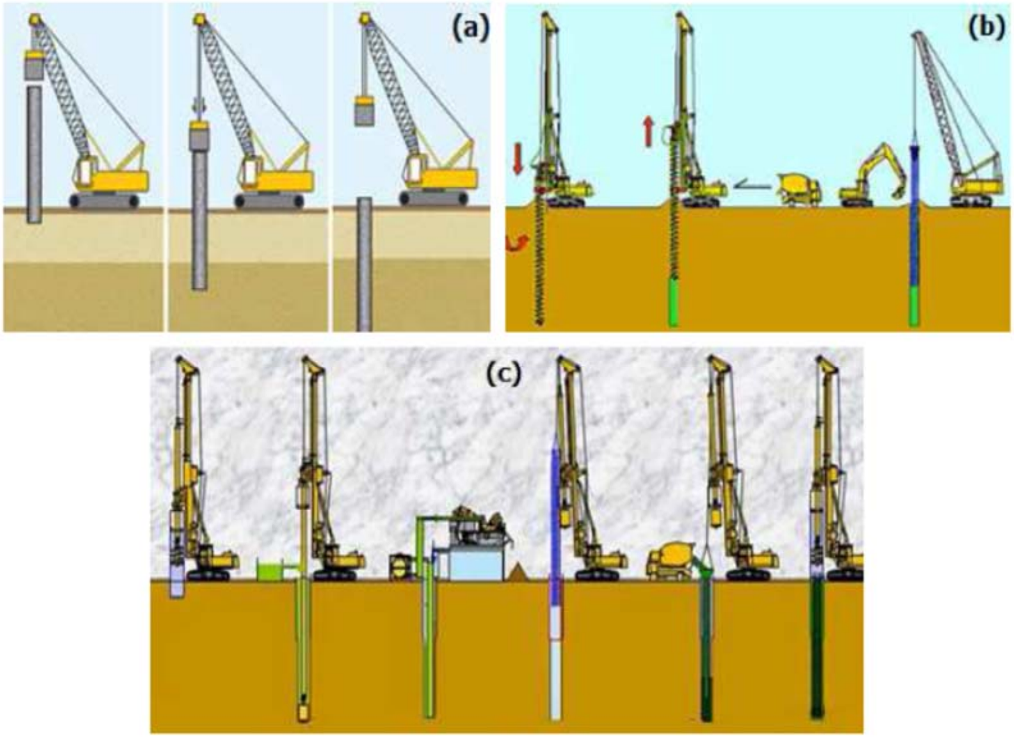

Figure (10): Type of foundation system. (a): driven piles, (b): CFA piles, (c): bored piles

Advantages of CFA Piles

The factors that have contributed to the choice of CFA piles in the project are:

- Simple foundation requirements: a large number of piles are commonly used in a compact area, primarily to support large concentrated dead loads.
- Speed of installation of CFA piles over other pile types.
- Increased use of design-build contracting in private work, in which contractors are highly motivated toward speed, economy and innovation.
- Increased requirements to minimize noise and vibrations from pile installation in heavily populated areas.
- Reluctance by many owners to utilize CFA piles because of concerns about quality control and structural integrity.
- Semi-displacement, resulting in lateral soil compression that increases final load bearing capacity.

Disadvantages of CFA Piles

The disadvantages of CFA piles compared to driven piles are:

- The available QA methods to verify the structural integrity and pile bearing capacity for CFA piles are less reliable than those for driven piles.
- CFA piles generate soil spoils that require collection and disposal.

Construction Process of CFA Piles

CFA piles are a type of drilled foundation in which the pile is drilled to the final depth in one continuous process using a continuous flight auger. The process is done in three phases:

Phase 1: While the auger is drilled into the ground, the flights of the auger are filled with soil, providing lateral support and maintaining the stability of the hole (Figure 11). A plug or hinged cap is located at the bottom of the auger that prevents soil from entering the hollow drill stem. The plug will then be ejected or open when concrete pumping begins (Figure 11(b)).

Phase 2: At the same time when the auger is withdrawn from the hole, concrete or a sand/cement grout is placed by pumping the concrete/grout mix through the hollow center of the auger pipe to the base of the auger (Figure 11(c)). Simultaneous pumping of the grout or concrete and withdrawing of the auger provide continuous support of the hole.

Phase 3: Reinforcement for steel-reinforced CFA piles is placed into the hole filled with fluid concrete/grout immediately after withdrawal of the auger (Figure 11).

Determination of the Number of Piles

The pile as part of a group has a different behavior from that of a single pile. Where groups of displacement piles are installed, significant improvements in capacity can be observed as a result of soil compaction and increased lateral stress in the ground (Brown et al., 2000; Van Impe et al., 1997). The efficiency coefficient of the pile group is given by Equation 6:

$$Ce = \frac{Q_{gu}}{N.Q_{ul}} \qquad (6)$$

The efficiency coefficient is given by the formula of Converse-Labarre (Chellis, 1961) shown in Equation 7:

$$Ce = 1 - \frac{2\arctan\frac{B}{S}}{\pi}\left(2 - \frac{1}{m} - \frac{1}{n}\right) \qquad (7)$$

The number of piles under the water tank (photo 1) was determined using Equations 6 and 7 by the two methods. The results are presented in Table 4.

CFA piles are most commonly installed as part of a pile group in a manner similar to that of driven pile foundations as illustrated in Figure 12. As in driven piles, the top of a group of CFA piles is terminated with a cap. Typical minimum center-to-center spacing is 3 to 5 pile diameters.

Table 4. Number of piles determined by MPT and CPT

Tests	MPT	CPT
Number of piles	25	25

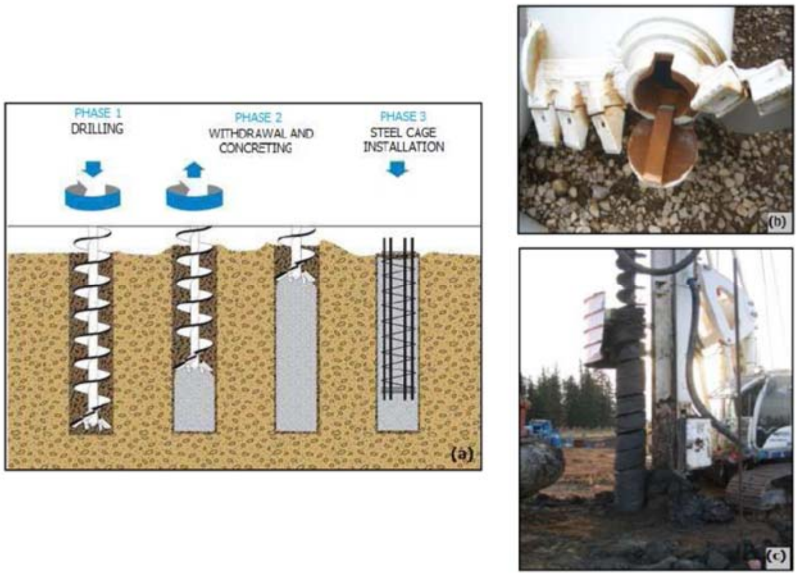

Figure (11): Schematic drawing of CFA pile construction

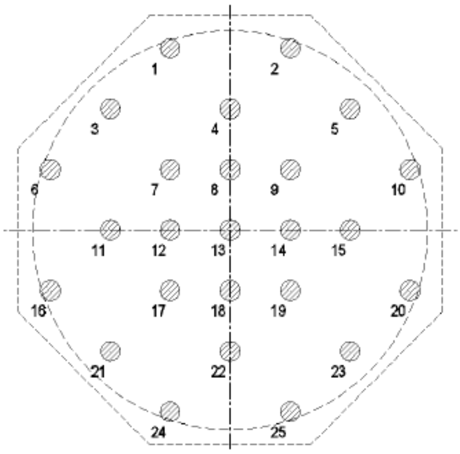

Figure (12): Piles' disposition under the tank floor

Photo (1): Construction of the water tank

CONCLUSIONS

A comparative study between several types of foundation systems was introduced from MPT and CPT. The following conclusions can be drawn from this study:

1. The results of MPT and CPT showed that the soil is compressible.
2. The pile bearing capacity values for the three types of foundation system (bored piles, driven piles and CFA piles) are almost the same.
3. The foundation system CFA type has a better bearing capacity. It is more appropriate for this case of soil.
4. The results of MPT and CPT confirm our choice of foundation system type CFA. This technology was chosen by the company on site.

NOMENCLATURE

Q_p	Ultimate limit of peak load	kN
kp	Bearing factor	-
ple*	Net equivalent limit pressure	MPa
Q_s	lateral friction limit load	kN
P	Perimeter of the pile	m
q_s (z)	Unit side friction limit at the height z	MPa
h	Height which actually carries lateral friction	m
q_{ce}	Equivalent peak static strength from CPT	Mpa
k_c	Bearing factor	-
A	Pile section	m²
C_e	Efficiency coefficient	-

Q_{gu}	Ultimate load bearing capacity of the group	kN
Q_{ul}	Ultimate load of individual pile	kN
N	Number of piles	-
B	Diameter of pile	m
S	Center-to-center spacing of piles	m
n	Number of pile rows	-
m	Number of piles in row.	-

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