# Two examples of CPT interpretation to define geotechnical profile

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ABSTRACT: This paper includes results from two experiences in Spain, where the employment of CPTu results, was the key to define the geotechnical profile. In one project CPTu tests were done in pairs with DMT tests. The joint interpretation of both tests improved interpretation in order to distinguish geotechnical levels with different properties. CPTu tests have been previously employed to define geotechnical and even sedimentological profiles (Devivenzi et al, 2004).

## 1 INTRODUCTION

This paper includes results from two experiences in Spain, where the employment of CPTu results, were the key to define the geotechnical profile. The first study was done for designing a highway in Medinaceli (Soria, Spain). The study area is geologically complex. It is situated in the occidental border of the Iberica mountain range where Triassic sediment in Germanic Facies appears. These sediments are mainly composed of clays with gypsum, classified as Keuper. Due to tectonic movements endorreic basins were generated. This basin has been filled by alluvial sediment related to the Jalón and Velarte rivers.

The highway will be built from Jalón river valley and parallel to the Velarte river valley. An embankment, 6 to 8 m high, has been projected in every basin the highway crosses. All these embankments will be built over a thickness of alluvial and Keuper sediments. The superficial alteration of Keuper clays makes it difficult to establish the depth of the alluvial sediment and the position of the Keuper sediment, in spite of their different geotechnical behavior. The contact position between the alluvial and Keuper clays is relevant in the highway design because it defined the depth of soil treatment to be applied to the embankment foundations.

The geotechnical study was based on mechanical borehole and CPT tests. A total of 11 CPT tests were done. At least one CPT was done in every endorreic basin studied. The analysis of CPT results has been the key to establish the contact between the alluvial sediment and Keuper clay to define the base of the proposed soil treatment.

In the second project, a geotechnical prospecting study was developed, whose final aim was the design of a high velocity railway. This study consisted of borings as well as CPT and DMT. A total of 16 CPT and 10 DMT test were done. The study area is constituted by highly deformable marsh sediments related to Guadalquivir River in the southwest of Spain. The peculiarity of this railway path is that it is close to the marsh border, so big differences in thickness of the marsh sediment and geotechnical behavior were expected.

The joint interpretation of CPT and DMT results was useful to define three different levels in the marsh sediment, in terms of its thickness, distribution and geotechnical behavior. The interpretation was also used to classify laboratory test results in these three levels and to evaluate the coherence in defining levels with different geotechnical behavior. This precision in soil profile allows a more accurate definition of soil improvement treatments. Also, the combination of results of CPT and DMT tests has been employed in settlement estimations. The methodology is described elsewhere (Arroyo et al, 2004; Arroyo & Mateos, 2006).

## 2 NAVARRA MOTORWAY (MEDINACELI-RADONA).

The geotechnical research was done for the project of a motorway in Medinaceli in the center of Spain. The motorway begins crossing over the Jalón river valley, where there is a thick deposit of soft alluvial sediment, and continuous along the valley of the Velarte watercourse. This is a small valley developed over Keuper sediment. Triasic materials in the center of Spain were sedimented in Germanic facies, so Keuper sediments are composed of clays with gypsum.

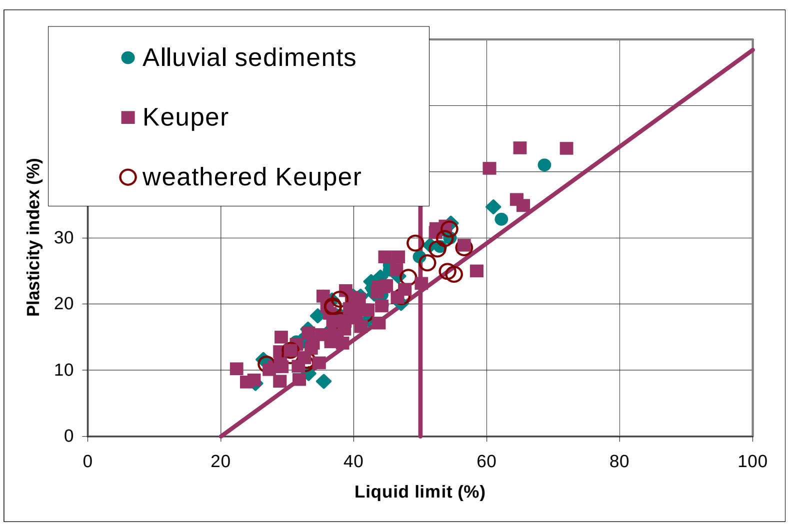


Figure 1. Casagrande chart for alluvial and Keuper sediments.

As the layout of the motorway goes by the Velarte valley, it crosses a series of endorreic basins where there is a considerably thickness of alluvial sediment. These sediments were formed from the Keuper materials erosion, so they are similar in color; granulometry and plasticity (see Figure 1). Moreover, the upper levels of Keuper sediments are weathered so their appearance is similar to that of alluvial sediment. As an example, a picture of a borehole core is shown in Figure 2. In the samples shown, there must be the contact between the alluvial and Keuper sediments. It is difficult to define accurately the contact position, because both sediments look quite similar. Nevertheless, their geotechnical properties must be different, although alluvial and weathered Keuper materials can be classified as soft soils.


Figure 2. Example of borehole samples showing transit between alluvial and keuper sediments.

The main part of the 12 km motorway studied is going to be built over embankments between 4 to 10 m high. The highest embankments are projected over the alluvial sediments in the endorreic basins. So, stability and deformability problems are expected. The soil improvement techniques designed to avoid these problems have been stone columns, prefabricated vertical drains and partial substitution of soft soil. In order to accurately define the depth of these treatments it was necessary to obtain a credible distribution of alluvial sediments and weathered Keuper in the geotechnical profile. The main tool to meet this objective was the CPTu. Also, mechanical boreholes, vane-tests, continuous dynamic penetration tests (DPSH) and pressuremeter tests were performed.

Figure 3 presents the closest CPTu profile to the borehole core shown in Figure 2. Behavior recorded of cone resistance ($q_c$), sleeve friction ($f_t$) and increments of pore water pressure, changes at 15 m depth. It means that the contact between alluvial and Keuper sediment is located at this position.

Revision of all the results obtained from the CPTu helped define the characteristic values of the CPTu records for each type of sediment studied, as it is shown in Table 1.

Table 1.Characteristic values of CPTu test for each type of sediments.

| Parameter | Alluvial sediment | Weathered Keuper sediment |
|---|---|---|
| SBT | 3 - 5 | 4 - 6 |
| $q_T$ (kp/cm$^2$) | 10 | 80 |
| $f_T$ (kp/cm$^2$) | 1 | 2 |
| FR | 5-6 | 4 |
| $N_{SPT}$ | 10 | > 20 |
| $s_u$ (kPa) | 50 | > 200 |

These values, although a simplification of the behavior of the studied soils, show that the geotechnical behavior of the alluvial sediment is clearly different from that of weathered Keuper sediment.

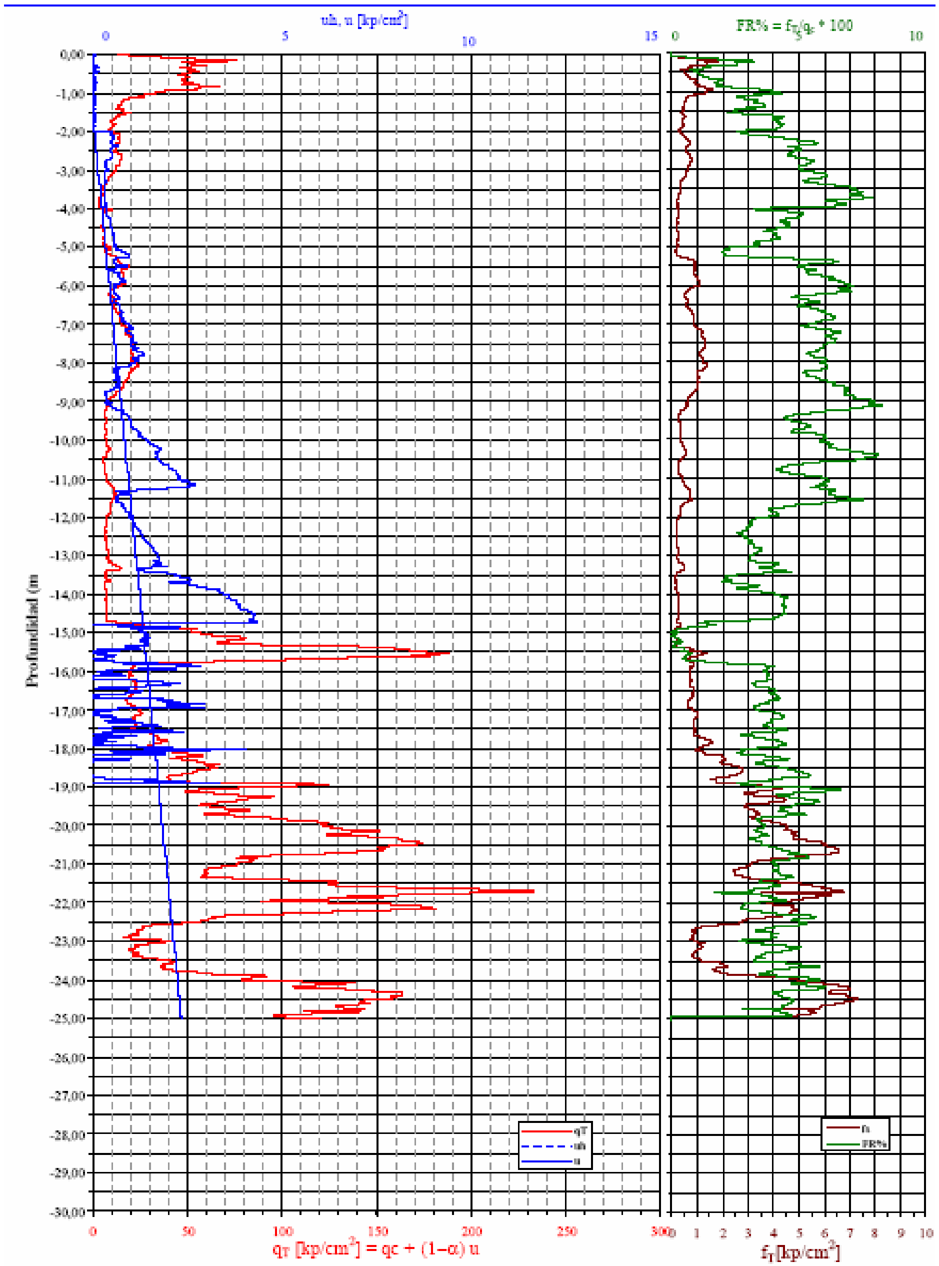


Figure 3. Results from the CPTU test closest to the borehole core shown in figure 2. (Note: $kp/cm^2 = kg/cm^2$)

The soil improvement treatments designed are being applied at this time, showing that predicted depth of very soft alluvial soil have been accurate.

## 3 HIGH VELOCITY RAILWAY (CABEZAS DE SAN JUAN – LEBRIJA. SEVILLA)

The second example is a project of a high velocity railway in Sevilla (south of Spain). The layout is developed just where the sediment of Guadalquivir marsh joins to the tertiary marl which edges the Guadalquivir river valley. The rail pathway is designed mainly over the marsh sediment, but due to the proximity of the tertiary hills, the thickness and consistency of this sediment are very variable. The heterogeneity in thickness and mechanical properties is probably due to the influence of continental geomorphologic and sedimentologic processes, mostly fluvial, in the border of the marsh basin jointed to marine processes. The fluvial dynamic has brought to the basin granular sediment and has kept in the cohesive levels higher humidity related to the actual fluvial net.

The research geotechnical campaign consisted of mechanical boreholes, dynamic penetration tests, CPTu and Marchetti dilatometer tests (DMT).

Interpretation of the stratigraphic profile was done initially from the borehole descriptions and the results of dynamic penetration tests. These tests were able to define the contact between the marsh sediment and tertiary marl underneath. Nevertheless, the deformability and heterogeneities in the marsh sediment were not precisely defined. The geological description distinguishes two levels in the marsh sediment: the first one was composed by sand and mud whose extension was almost continuous along the bottom limit of the marsh sediment. The second level was placed over the sand-mud layer and was composed by dark grey clay, very soft and plastic. The total thickness of the marsh sediment is between 8 to 10 m, with local sub-basins where the thickness increases up to 20 to 50 m.

The analysis of the results of other in situ test, specially CPTu and DMT tests, was the key to define another two sublevels inside the marsh sediments. Due to the fact that CPTu and DMT tests were done in pairs, a joint interpretation of the results was done. Values to correlate were the cone resistance measured in the CPTu test and the deformation modulus (M) obtained from the DMT tests. There are published correlations to obtain the deformation modulus of a soil from the cone resistance measured in CPTu tests. These correlations are different if the soil is cohesive or if it is granular (Lunne et al, 1997 & Marchetti, 2002).

In this study the work was carried out in a reversal way: from the data obtained by the CPTu and DMT records the value of a proportionality parameter ($\alpha$) between cone resistance and deformation modulus, for each pair of tests, was obtained.

As an example, in Figure 4 results from three tests are included. CPT4 was the closest test to DMT6, meanwhile, CPT12 were performed not so close to DMT6. Observation of these data allows us to define at least three levels in the marsh sediment:

- An upper level in which the relationship between the deformation modulus and cone resistance is high ($\alpha > 18 – 20$).
- An intermediate level where cone resistance and deformation modulus are low and the relationship between them is also low ($\alpha < 5$).
- A lower lever with a relationship between the deformation modulus and cone resistance growing until values over 20.

Next, from the analysis of all results obtained along the railway studied it was possible to differentiate four sublevels with different geotechnical properties. These four levels are from bottom to top:

- $QM_1$ .- This is a granular level mainly composed of sand and sometimes mud. It extends almost continuously along the bottom limit of the marsh sediment.

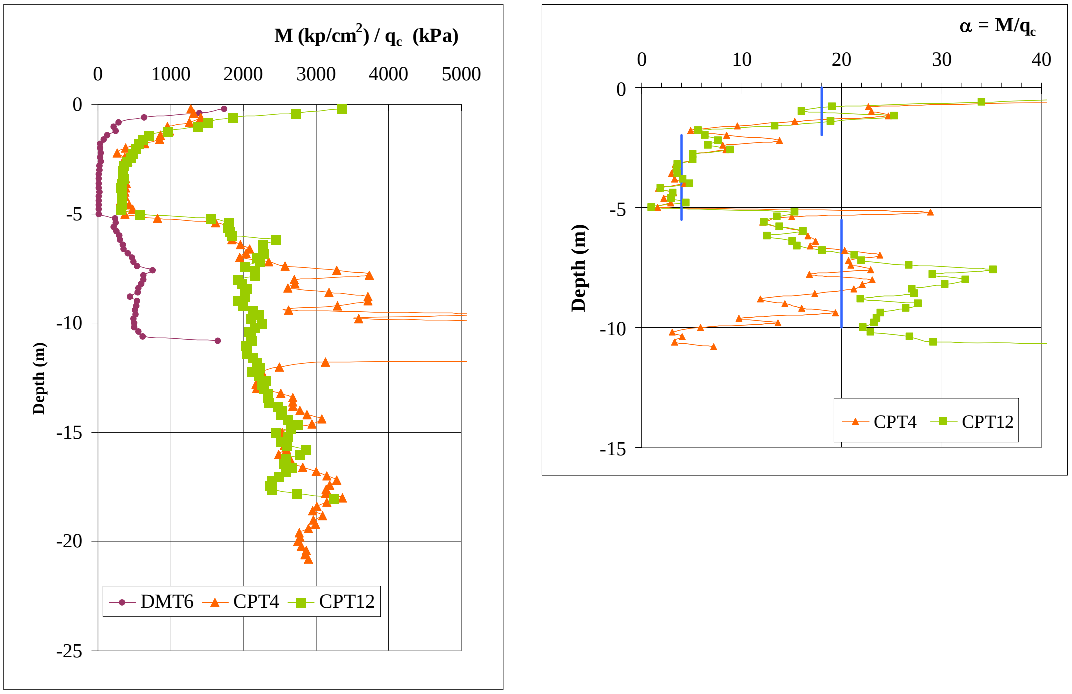


Figure 4. Example results from CPT and DMT.

- $QM_2$ .- Second level is mainly composed of clay. It is the least deformable level of the marsh sediment. It is formed of lightly overconsolidated clays. It shows smaller void ratio values and less humidity than clays overlying.
- $QM_3$ .- The fundamental difference between third and second level is deformability. These clays are highly deformable; they show high void ratio values and humidity. They appear continuously under the superficial level but its thickness is very variable between 4 to 25 m. Areas where the thickness is big are related to actual water streams that bring water to the area, helping to keep high humidity in this clay levels.
- $QM_4$ .- This is the superficial level. It is composed by the same clays described in $QM_3$ but in an overconsolidated state due to desiccation. Its thickness is between 3 to 4 meters.

As an example of the lateral variability of facies in marsh sediment is shown in Figure 5 that shows two groups of CPTu-DMT pairs in a short length (< 1000 m) along the railway.

Different behavior recorded by the tests allows defining the distribution of levels in marsh sediment with different geotechnical properties along the railway studied. This could not have been done just with the description of boreholes and the resulting profile is shown in Figure 5.

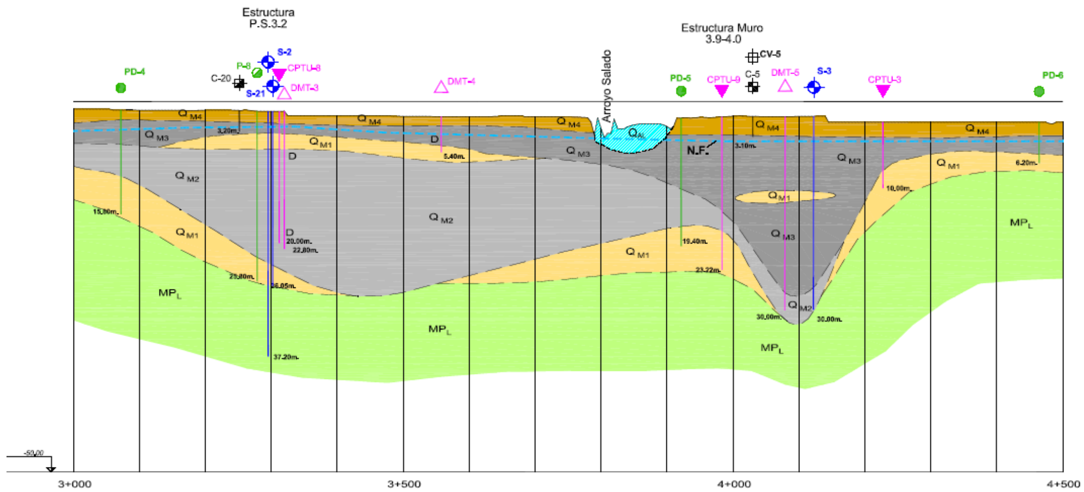


Figure 5. Example of geotechnical profile.

Once defined geotechnical level from the in situ test results, the laboratory testing was arranged for the marsh levels defined. Results are shown in Table 2, where the differences in fine content and plasticity between clay and sandy levels can be observed; dry density and humidity in clay levels of different shear resistance ($S_u$) and deformability ($C_c$) also change

Table 2. Geotechnical parameters of different facies in marsh sediments.

| Geo-tehnical level | $N_{SPT}$ | Fine content (%) | Plasticity | | | $\gamma_d$ | W | $S_u$ | OCR | $C_c$ | $C_s$ | $c_v$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | LL | LP | IP | KN/m$^3$ | % | KPa | | | | cm$^2$/s |
| $QM_1$ | 35 | 60 | 44 | 24 | 20 | 17,3 | 21 | 175 | | | | |
| $QM_2$ | 20 | 92 | 55,5 | 27,5 | 28 | 14,8 | 30 | 120 | 2,4 | 0,19 | 0,06 | 2,46*10$^{-4}$ |
| $QM_3$ | 6 | 92 | 63 | 32 | 31 | 12 | 44 | 28 | 0,68 | 0,36 | 0,09 | 1,67*10$^{-4}$ |

Finally, the improvement in profile definition was fundamental in the soil improvement treatments designed along the railway.

## 4 CONCLUSIONS

Two examples have been presented that show how CPTu results helped define accurate geotechnical profiles. This improved definition is related with differentiations of levels with different sedimentological genesis but very similar in appearance due to the fact that the more recent sediments came from the oldest. The second example corresponds to differentiation of facies in marsh sediments.

In both cases the precision of geotechnical profiles obtained allows a more accurate design of soil improvement treatments that are necessary to the correct behaviour of the embankments in the two projects.

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