Geotechnical characterization of an earthfill constructed from schist residual soils

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ABSTRACT

Earthfills are anthropogenic soil massifs that were originated by different processes than those observed in traditional soil mechanics, thus revealing some deviations to the behaviour of common natural soils. The common characterization of earthfills is based in discontinuous testing such as nuclear densimeter gauge used together with laboratory compaction tests and the stiffness evaluation obtained from plate load tests, which does not give answers in the context of strength evaluation (Cruz et al. 2008; Cruz et al. 2006).
The case study presented herein refers to the geotechnical characterization of an earth fill composed by evolutive materials obtained from the de-structuration of schists, which has developed excessive settlements. The performed geotechnical characterization consisted in boreholes and regular SPT tests, Dynamic Probing (DPSH), Piezocone (CPTu) and Marchetti Dilatometer (DMT) tests, as well as triaxial, shear box, consolidation and identification tests. DMT and CPTu tests were selected not only to obtain strength and stiffness parameters, but also because of its ability to access stratigraphy and unit weights. The whole set of obtained results are presented, compared and discussed, revealing a clear convergence between results as well as some interesting particularities that may be useful in fill characterization.

Keywords: Evolutive soils; earthfill; in-situ tests; geotechnical characterization.

1. Introduction

The case study presented herein refers to the geotechnical characterization of an earth fill composed by evolutive materials obtained from the de-structuration of schists, which has developed excessive settlements.

Earthfills are antropogenic soil massifs that were originated by different processes than those observed in traditional soil mechanics, thus revealing some deviations to the behaviour of common natural soils. The common characterization of earthfills is based in discontinuous testing such as nuclear densimeter gauge used together with laboratory compaction tests and the stiffness evaluation obtained from plate load tests, which does not give answers in the context of strength evaluation (Cruz et al. 2008; Cruz et al. 2006). The presented study aims to compare the results obtained by several in-situ tests with support in laboratorial tests.

2. Background

The fill under study is part of the motorway network operated by Ascendi – A13, located at Pk 201+400 in the outskirts of Coimbra, near by the Rio Ceira. This earth structure is within a tectonic complex area characterized by the major fault Porto-Tomar that deeply marks the region. From the geomorphologic point of view, the area is within a uplift block, designated by “Horst do Senhor da Serra”. The fill is placed over the metassedimentar deposits of Ossa Morena zone, designated by “Série Negra”, which consists in black schists interbedded with metagrawacks in layers of significant thickness. In general, these materials present high degrees of weathering and fracturaction. In Fig.1 the extract from the sheet 19-D COIMBRA-LOUSÃ of Carta Geológica de Portugal (1:50 000) is represented, while Fig. 2 shows the earthfill in Google.

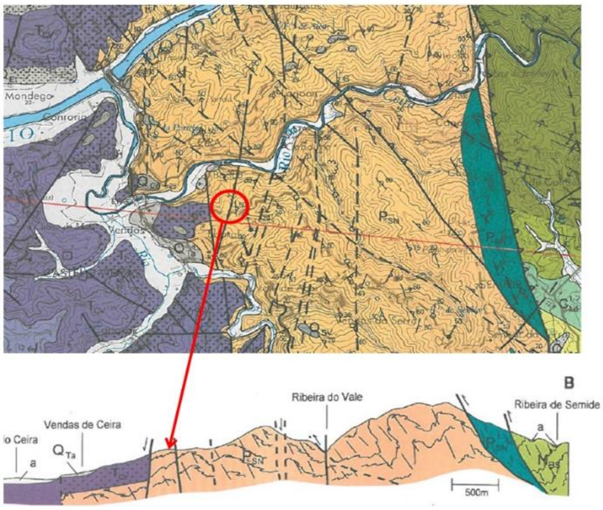

Figure 1. Extract from sheet 19-D COIMBRA-LOUSÃ of Carta Geológica de Portugal (1:50.000).

The fill was constructed using materials that result from an excavation located in the neighborhood, respecting the general criteria related with the fill materials. To characterize the earthfill, a geotechncial campaign was settled, consisting in 15 bore-holes, 122 SPT, 13 DPSH, 3 CPTu, 2 DMT, 8 in-situ permeability tests and several laboratory tests (identification, consolidation, shear box and triaxial). The in-situ tests were performed according to ISO 22476 Geotechnical investigation and testing - Field testing, Parts 1, 2, 3 and 11, respectively CPTu, SPT, DPSH and DMT tests. Laboratory tests were performed in the Central Laboratory of the company Mota-Engil Engenharia e Construção S.A and in the Civil Engineering Laboratory of IPG (Guarda Polythechnic Institute), according to euro norms and the Eurocode 7 – Part 2 "Geotechnical design assisted by testing: Laboratory testing. Both laboratories are certified by the Portuguese Institute of Quality – IPQ, according to NP EN ISO/IEC 17025. The obtained results and discussion will be presented further ahead.

Figure 2. Google image of the earthfill.

3. Obtained results

3.1. Identification and physical characterization

The obtained bore-holes information revealed the following geologic model, from top to bottom (Fig. 3):

1) Earthfill composed by silty sand intercalations of black schist (slate) and quartz-feldespar brown schist soils (Fig. 4 and Fig. 5), both coming from the same excavation. The thickness of the fill varies within 3 and 35 m; the characteristics of this unit is discussed along this paper. Brown schists are common materials for fills in Portugal, while black schists are not commonly used.

2) The foundation of the earthfill correspond to residual soils from the weathering of schists, namely silty sands to sandy silts, sometimes clayey sands with thicknesses that are usually lower than 6 m, globally characterized by uncorrected N_{SPT} values within 20 and 60 blows to which corresponds $(N_1)_{60}$ within 13 and 60.

3) Below the residual soils the massif becomes decomposed (W_5) to highly weathered (W_4), characterized by N_{60} higher than 60 blows, respectively with penetration lower than 15 cm and within 15 and 30 cm.

Basic laboratory tests reveal that the fill is constituted by granular soils with fine content lower than 30%, no-plastic (brown schists) or with plasticity index lower than 10% (black schists), classified by the Unified ASTM classification respectively as SM and SC to SC-SM, as well as A-2-4 to A-2-6 following the AASHTO classification. Grain size distributions reveal passing percentages on sieve #200 within 13 and 28% (Fig. 6) Both schists are within the evolutive soils group, but with different degrees of evolution under load.

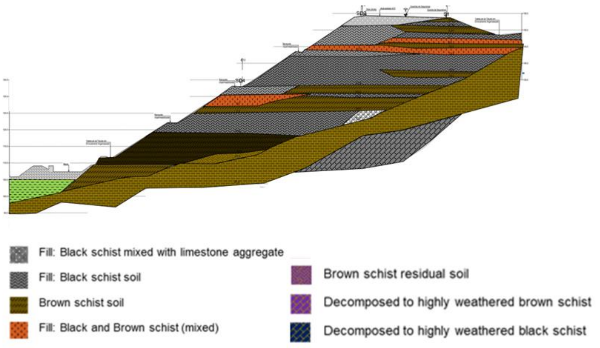

Figure 3. Illustrative cross section of the earthfill.

Figure 4. Black schists in the earthfill.

Figure 5. Brown schists in the earthfill.

Fig. 7 and Fig. 8 reveal their responses after being submitted to dynamic (Proctor tests) and static loads (consolidation tests with load stages up to 800 kPa). Note that tested samples correspond to the in-situ materials after compaction, where some evolution had already occurred. Nevertheless, they still reveal evolutive capacity under dynamic loads with higher level in black schists than in brown schists (10 to 20% finer), while in the case of static loads only black schists present evolution becoming 5 to 10% finer.

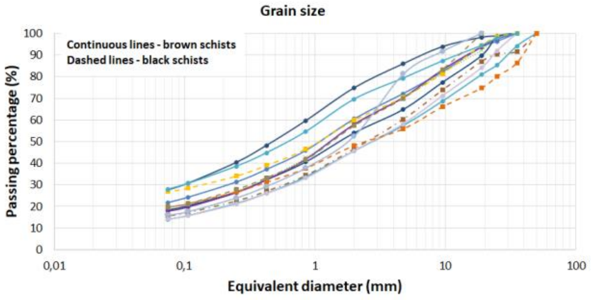

Figure 6. Grain size distributions.

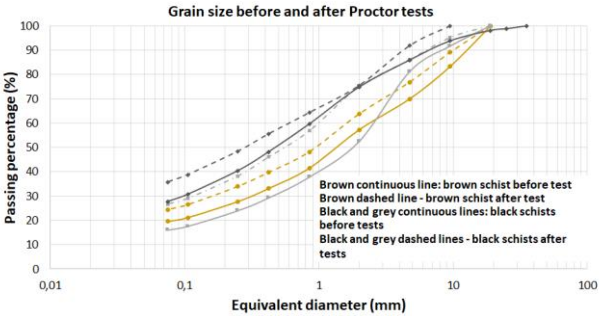

Figure 7. Grain size before and after Proctor test.

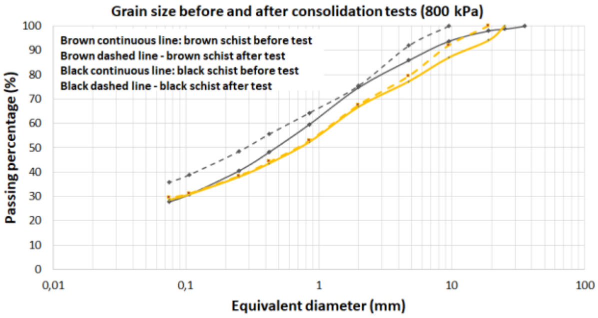

Figure 8. Grain size before and after consolidation test.

From the physical indexes point of view, laboratorial characterization revealed moisture contents within 10 to 15% lower than plastic limits (within NP to 25%) and liquid limits (NP to 30%). Density of solids is between 2.78 and 2.84, dry unit weights from 17.5 and 19.5kN/m^3, void ratios of 0.4 and 0.6 and degrees of saturation between 40 and 60%, with no relevant differences observed in the two types of schists (Fig. 9 and Fig. 10).

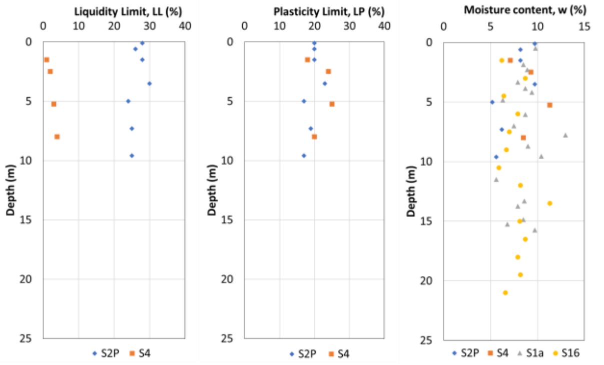

Figure 9. Moisture content tests.

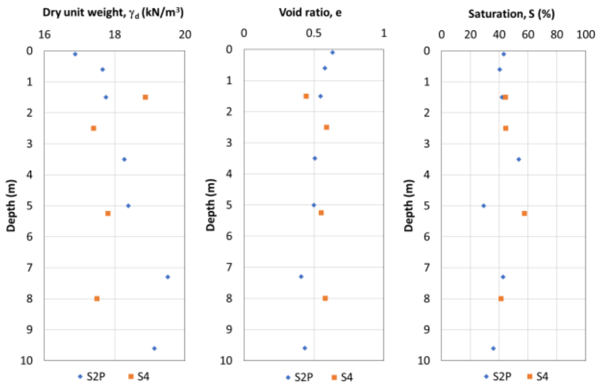

Figure 10. Physical tests.

3.2. Triaxial tests

Laboratory mechanical tests included triaxial, shear box and consolidation tests to characterize both types of schists. Due to the presence of coarse elements within the fill (Fig. 11), these tests had to be performed in remolded samples to avoid scale effects. The remolding was executed following the representative unit weights of the fill, removing the coarse materials.

Figure 11. Selection of material for triaxial testing.

The results obtained in laboratorial tests can be summarized as follows:

1) Compressibility indexes (Cc) of both schists are represented by the same range, around 0.10; the secondary compression is small, represented by $c_\alpha/(1+e)$ within 0.0020 to 0.0024 and 0.0006 to 0.0012, respectively related with black and brown schists;
2) Consolidated undrained triaxial tests performed in black and brown schist samples in saturated conditions at confining stresses between 100 and 450 kPa did not show a strength peak in the deviatoric stress-axial strain space;
3) All the consolidation tests revealed the rapid stabilization after loading, meaning a fast dissipation of pore water pressure sustaining the field results;
4) In saturated conditions, the shear strength parameters obtained in triaxial revealed different results, with brown schists showing a cohesion intercept of 10.5 kPa and a angle of shearing resistance of 36.8º, while black schists are represented by a cohesion intercept of 2.6 kPa

and 32.1° for the angle of shearing resistance (Fig. 12 and Fig. 13);

5) The moduli decay of both schists obtained from triaxial data is represented in Fig. 14 and Fig. 15, revealing identical pattern with results slightly lower in the black schists;
6) Fig 16 and Fig. 17 show the samples after testing.

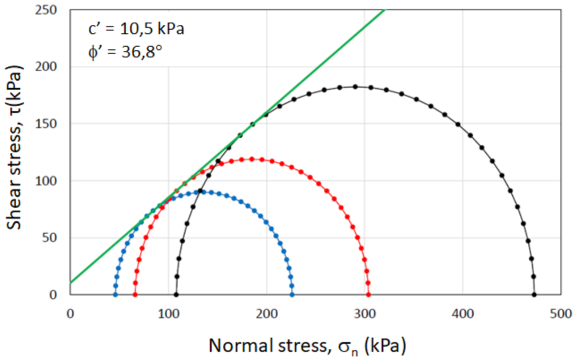

Figure 12. Mohr-Coulomb representation of brown schists.

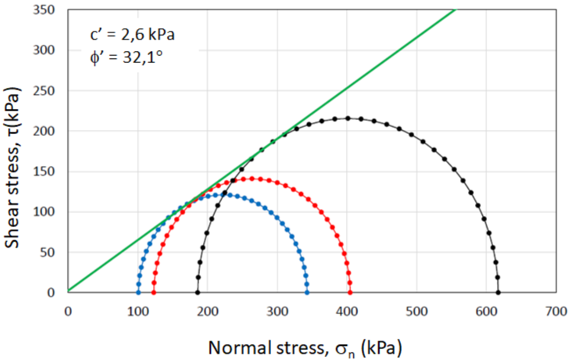

Figure 13. Mohr-Coulomb representation of black schists.

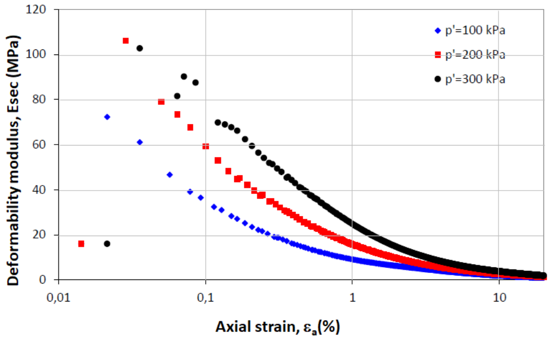

Figure 14. Modulus decay curves of brown schists.

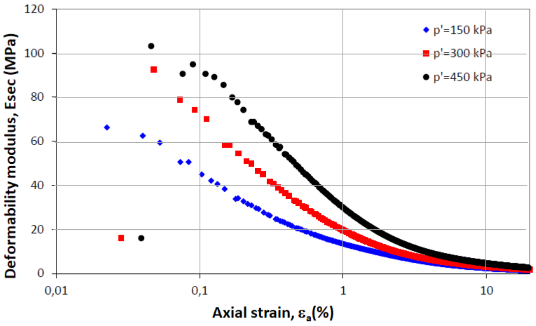

Figure 15. Modulus decay curves of black schists.

Figure 16. Samples of black schists after testing.

Figure 17. Samples of brown schists after testing.

3.3. In-situ tests

Five types of in-situ tests were executed during the field campaign, namely SPT, DPSH, CPTu, DMT and permeability (Lefranc) tests. In what follows, the obtained results are presented, discussed and compared between each other, as well as with laboratory testing.

DMT and CPTu tests give information about the nature of the soil, although it is obtained through a mechanical response of the soil and not by grain size analysis. The results obtained in both tests are presented in Fig. 18, revealing the presence of silty sands to sandy silts completely converging to the laboratorial grain size distributions presented above.

To express the complete set of correlations related within this paper would be impossible for space reasons, thus only references will be mentioned along the test. DMT and CPTu type of soil interpretations were obtained according to Marchetti (1980) and Robertson & Cabal (2015), respectively.

CPTu and DMT test results converge to the laboratorial results in the case of local unit weights, although with slightly lower DMT results (Fig. 19). This is important to be validated in these two tests once the unit weight is the base for evaluating in-situ stresses, which in turn are required for deducing DMT and CPTu intermediate parameters (e.g K_D and normalized CPTu Q_T and F_R). DMT and CPTu unit weights were obtained according to Marchetti and Crapps (1981) and Robertson and Cabal (2015), respectively.

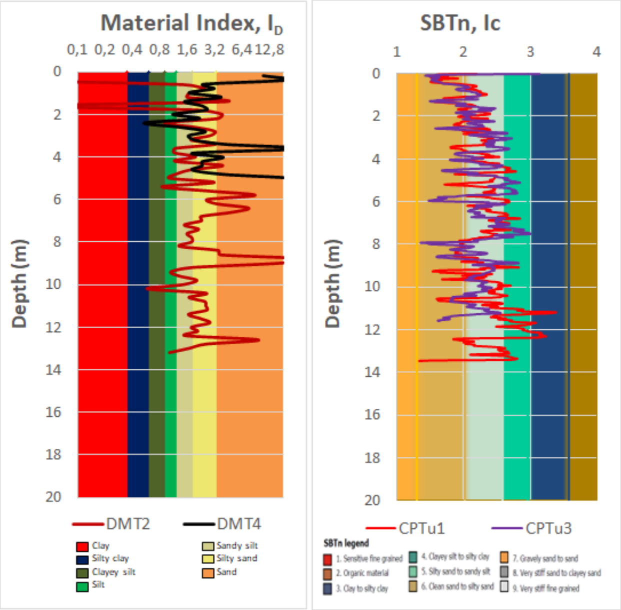

Figure 18. DMT and CPTu soil identification.

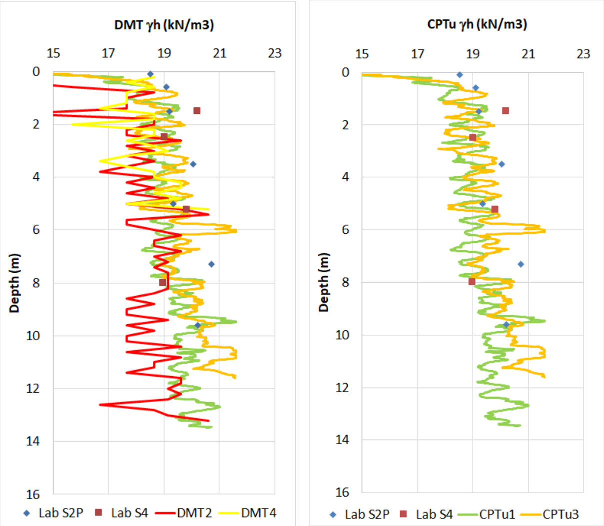

Figure 19. Unit weight from DMT and CPTu tests.

In relation to earth fill permeability, results obtained in Lefranc permeability tests fall within 10^{-5} a 10^{-7}m/s, confirming the CPTu results obtained by correlation with mechanical parameters (Robertson and Cabal 2015), as ilustrated by the profiles in Fig. 20. The results were also confirmed by the rates obtained in consolidation laboratorial phases (triaxial, shear box and consolidation tests).

Soil behaviour type (SBT) charts of DMT and CPTu tests reveal some more global information (Fig. 21 to Fig. 24) that fits in the laboratory obtained ranges. In the case of DMT the earthfill soils are medium dense to dense, coarse grained mostly drained although transitional behaviour was identified. The behaviour in shear is mostly dilative, although some contractive response was assigned. In turn, the most part of CPTu soil type results are within groups 4 (clayey silt to silty clay), 5 (silty sand to sandy silt) and 6 (sand to sandy silt). The representation in Robertson SBTn chart (Robertson and Cabal 2015) show that generally the crossed profile is classified as overconsolidated, which is in line with expected situation of an earthfill soils subjected to compaction. In terms of global behaviour, CPTu chart confirm the mostly drained dilative behaviour identified in DMT interpretations.

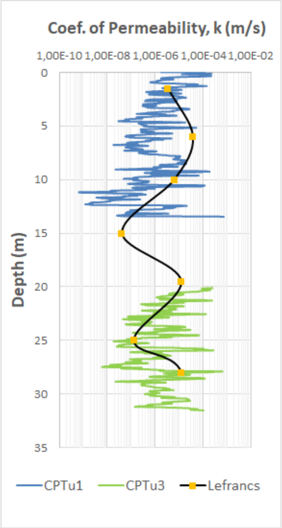

Figure 20. Lefranc tests and CPTu permeability profiles.

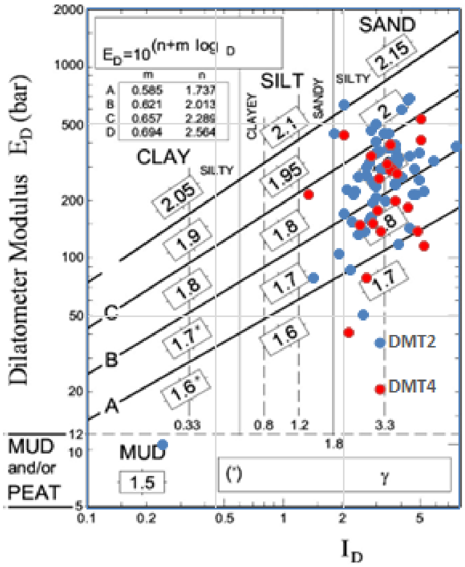

Figure 21. Type of soil and density according to DMT tests.

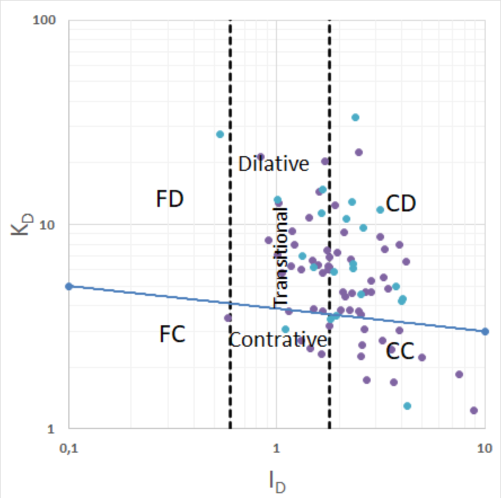

Figure 22. Drainage type and behaviour in shear according to DMT tests.

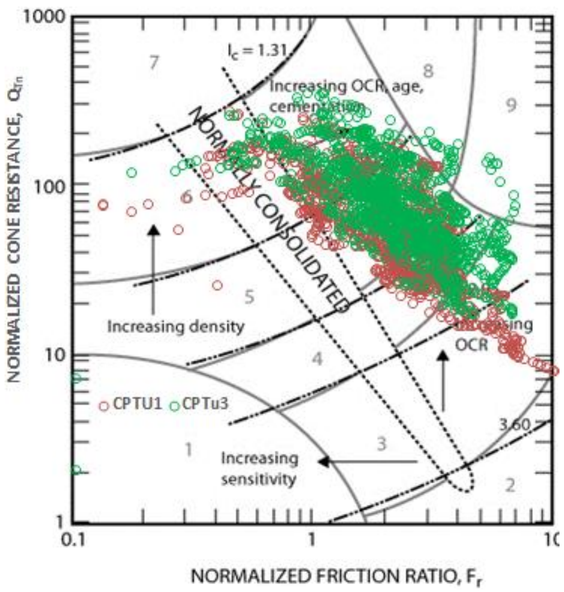

Figure 23. Soil classification according to CPTu tests.

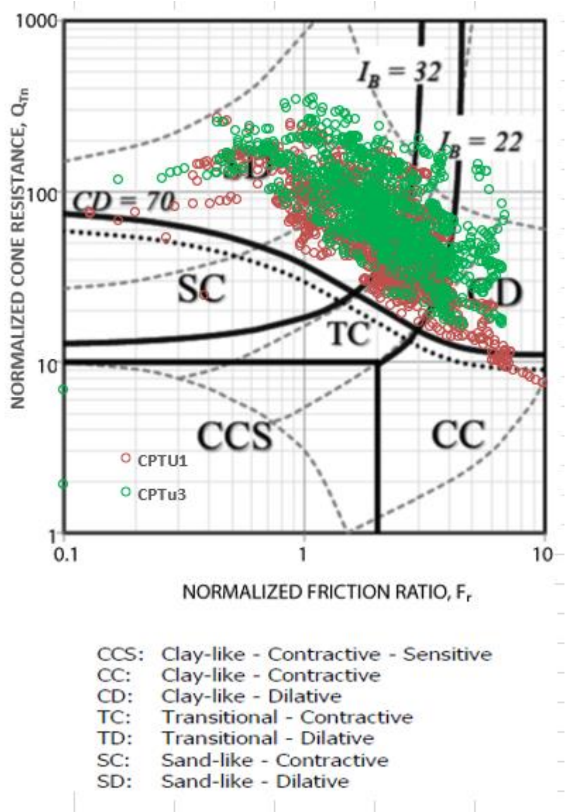

Figure 24. Drainage type and behaviour in shear according to CPTu tests.

The overall dynamic results represent medium dense (upper part) to dense (lower part), according to the classification proposed by Skempton (1986), confirmed by the relative density obtained in CPTu tests (Robertson & Cabal 2015), as shown in Fig. 25 and Fig. 26.

From the mechanical point of view, the application of common correlations dedicated to sedimentary transported soils, produce similar results in the whole set of in-situ tests. Dynamic test results (SPT and DPSH) where obtained with energy controlled, thus results were corrected for obtaining $N_{60}/(N_1)_{60}$. Similar corrections were applied to DPSH results, with the exception of the bore-hole influence that has no meaning in the current test.

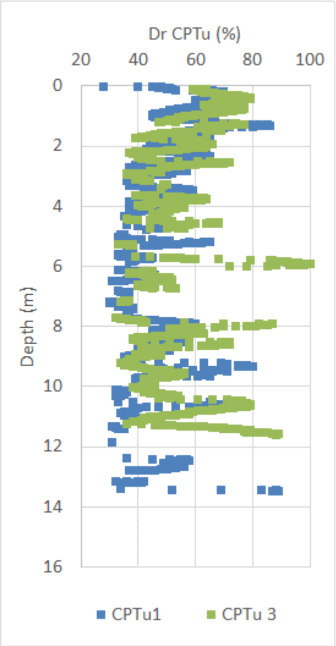

Figure 25. Relative density according to CPTu tests.

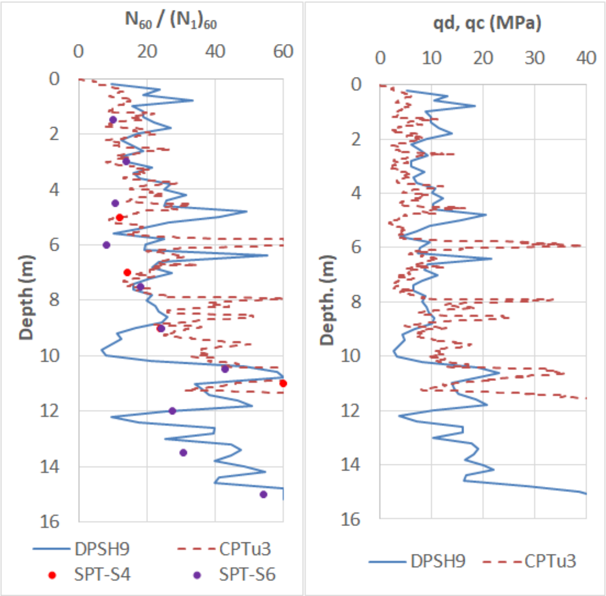

Figure 26. Dynamic profiles: a) $N_{60}/(N_1)_{60}$; b) q_d/q_c.

Fig. 26 illustrates the good convergence of results obtained in SPT and DPSH tests. In the same figure N_{60} deduced from CPTu data (Robertson and Cabal 2015) is included, which fits in the same range of the dynamic tests. Furthermore, dynamic and static point resistances follow the same pattern with depth with the ratio qc/qd globally equal to 0.7. Another interesting aspect is the peak structure revealed by all these tests that is compatible with a compacted structure, where the peaks are related to the maximum stiffness provoqued by the compact roller, typically 20-25 cm below the surface of each layer. In other words, the difference between two consecutive peaks is related with the compaction layer thickness.

The angles of shearing resistance obtained in the 4 test types (Fig. 27) are very similar, with good convergence between CPTu and dynamic tests, while DMT's fall within the same interval, but presenting higher scatter. As presented above, triaxial tests pointed out to results between 32 and 37º which are in line with the dynamic and CPTu test results and in a narrower band in comparison with DMT results. However it should be noted, that triaxial tests were performed under saturation conditions, while natural (unsaturated) conditions are adressed to the field tests. The results followed the Decourt (1989) correlation in the case of SPT and DPSH tests, Marchetti (1997) in DMT tests and Robertson and Cabal (2015) in CPTu tests.

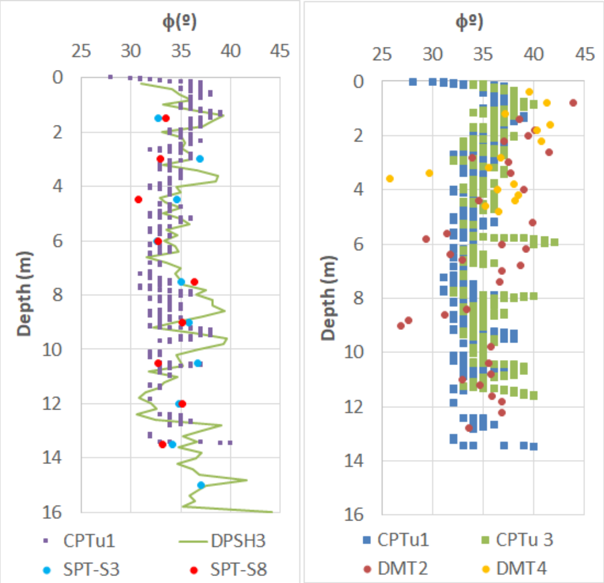

Figure 27. Profiles of angles of shearing resistance.

The comparison between moduli obtained in the 4 test types fit within the same range, with CPTu generally higher than dynamic and DMT tests and also presenting a higher range of variation (Fig. 28). The results were based in the Decourt (1992) correlation in the case of SPT and DPSH tests, Marchetti (1980) in DMT tests and Robertson and Cabal (2015) in CPTu tests.

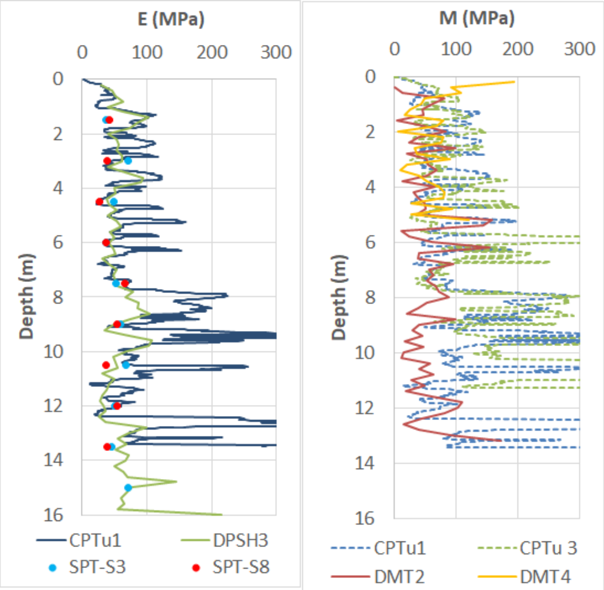

Figure 28. Stiffness profiles: a) Deformability Modulus; b) Constrained Modulus.

However, it should be said that moduli comparisons are complex because the strain level associated to each test can be quite different (DMT's lower than CPTu's, which in turn are lower than dynamic's) and DMT is a stress-strain test while CPTu and dynamic tests are purely strength tests. According to this, for stiffness evaluation DMT is a much more reliable than the other three, followed by CPTu, since static tests introduce lower level of disturbance when compared with the dynamic ones. The constrained modulus (M) obtained by DMT tests fit globally within 30 and 90 MPa, corresponding deformability moduli between 25 and 75 MPa if a poisson coefficient of 0.3 is considered. When compared with triaxial decay curves, for similar confining stresses (within 1 and 150 kPa) the related axial strains fits globally within 0.03 and 0.4% (Fig. 29 and Fig. 30), which fits the proposal of Amoroso et al. (2014) for sedimentary sand deposits.

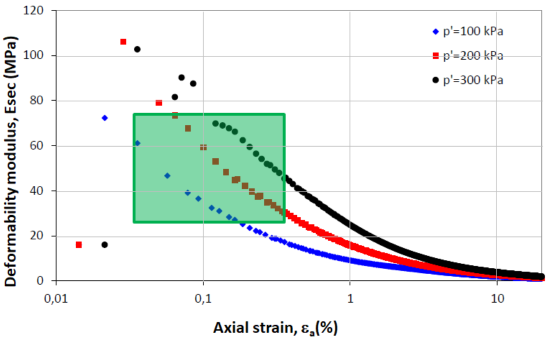

Figure 29. DMT and triaxial moduli in brown schists.

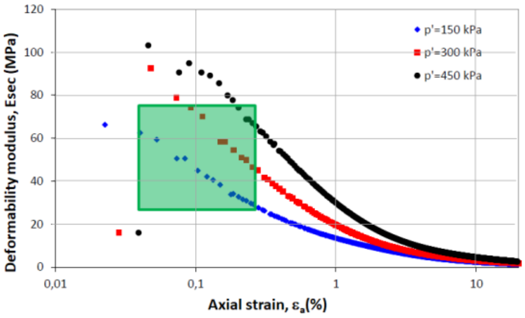

Figure 30. DMT and triaxial moduli in black schists.

In Fig. 31 the representation of constrained moduli obtained in CPTu and DMT tests compared with the triaxial results is represented, with DMT showing a much better adjustment. Once again, the peak structure of the profiles is observed, highlighting their capacity to detect the stiffness variation within each compacted layer.

Taking into account both in-situ and laboratory results, the earthfill under study can be globally classified as a drained medium dense to dense silty sand to sandy silt soil represented by unit weights within 17.5 a 20.5 kN/m^3, relative densities between 30 and 60%, angles of shearing resistance from 32 to 38º with mostly dilative behavior in shear and deformability modulus (E) within 25 and 75 MPa to which corresponds a constrained modulus (M) ranging from 30 to 90 MPa.

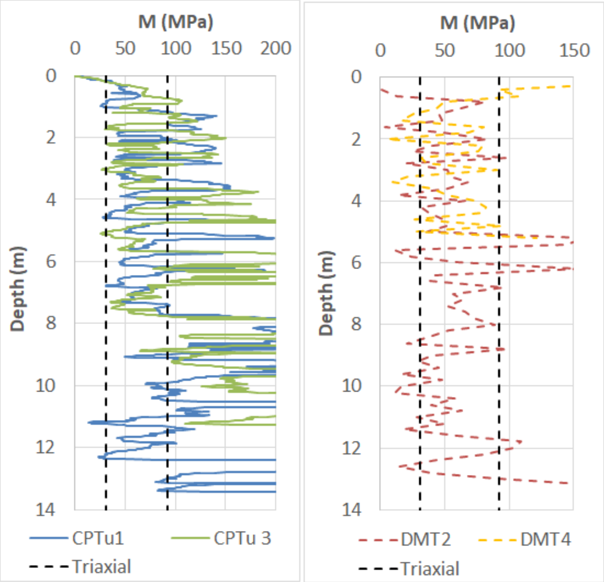

Figure 31. DMT and CPTu moduli profiles compared with triaxial ranges.

4. Conclusions

Earthfills are originated by human construction, with important differences when compared with natural sedimentary deposits, thus it is important to validate the common interpretations of in-situ tests dedicated to natural deposits. The study presented herein was based in an extensive laboratorial and in-situ campaign performed in unusual materials (black schists) and aimed a full mechanical characterization of the earthfill soils. In general, the overall in-situ geotechnical parameters obtained by the usual correlations dedicated to sedimentary soils compare well between each other, namely SPT and DPSH results, DPSH dynamic point resistance and CPTu point resistance, as well as several parameters obtained from CPTu and DMTs.

Stratigraphy obtained via CPTu and DMT reveal convergent strata related with the identification and the unit weights, both agreeing with laboratory tests, while CPTu permeability obtained by the mechanical correlations clear converges towards Lefranc permeability test results.

From the strength perspective, dynamic and static penetrometers and DMT tests revealed overlapping derived profiles of angles of shearing resistance, which are supported by the laboratory results. Moreover, DMT and CPTu based soil behaviour charts (SBTn) give twin information about density, drainage response and behaviour in shear, also supported by the obtained laboratory test results.

Stiffness behaviour is more complex and difficult to compare because tests work at different strain levels and apart from DMT, all the other tests are not stress-strain tests. The obtained results show the convergence between DMT and triaxial tests, while dynamic and static penetrometers reveal the expected lower degree of comparability.

The performed study highlights the usefulness of integrating CPTu and DMT tests in earthfill current characterization. In fact, both tests convergently identify the soil profile, estimate density and the consequent strength. Complementary, CPTu tests give valuable information about drainage and permeability, while DMT covers efficiently the stress strain response with higher quality than can be offered by common penetration tests. The experience also showed that dynamic tests can be easily mixed with CPTu and DMT.

The geotechnical survey presented herein was decisive to understand the strength and stiffness behaviour of the fill and design the consequent rehabilitation solution.

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