Comparison of soil modeling using CPT and DMT- a case study

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ABSTRACT: A site investigation campaign using cone penetration test (CPT) and dilatometer test (DMT) was carried on alluvial deposits of medium stiff silty clay with occasional sand and gravel at a site located in Gemlik, Turkey. Data obtain from CPT's and DMT's were used for subsoil geotechnical modeling. Soil classification, undrained shear strength, friction angle, compression modulus and shear wave velocities are compared for the whole site model and between closely located investigation pairs obtained using both in-situ measurement techniques. Soil models are also supported with SPT data and laboratory test results. As a result, a comparison of the models is critically evaluated for this specific case.

1 INTRODUCTION

The interpretation of geotechnical characteristics can be obtained with laboratory test data on high quality samples. However, cost and time required for performing laboratory tests and the discrepancies from accuracy related to soil disturbance and limited number of tests draws more attention to the in-situ tests for design and analysis. In this paper the results obtained from cone penetration tests (CPT's) and dilatometer tests (DMT's) performed at a site for the design of a newly planned hot reverse mill structure within the Borçelik Steel Factory located in Gemlik, Turkey are presented. The objective of this work is to compare the subsoil modeling predicted from both of these in-situ tests.

It could be stated that the extensive utilization of CPT in Turkey, is more recent compared to Europe gaining more recognition since 1970's for general soil investigation and foundation design purposes for various kinds of civil engineering structures (Durgunoglu and Togrol, 1974, Durgunoglu and Togrol, 1995). The first usage of CPT in Turkey was realized in late 1950's and since then, development on the application technique was realized. However, its application is generally limited to university and state funded research projects (Emrem, 2000). On the other hand, utilization of Marchetti's (DMT) Dilatometer is a rather recent in-situ testing method in Turkey (ZETAS, 2008).

The CPT provides two separate readings with depth, including; unit cone tip resistance (q_t) and unit sleeve friction (f_s), whereas the dilatometer (DMT) reflects different two readings compared to CPT, namely; the lift-off or contact pressure (p_0) and expansion pressure (p_1). Within the scope of this case study, soil classification, geotechnical parameters namely undrained shear strength, friction angle, deformation modulus, and shear wave velocities determined based on both in situ tests, are compared for the whole site and for closely located pairs. Further details of the data and the case study are presented by Aykin (2009).

2 LOCAL GEOLOGY AND GROUND WATER CONDITIONS

The subject site is mainly covered with asphalt and 2.0m thick controlled filled underneath the asphalt layer. Below the fill, an alluvium layer having varying thickness and properties is encountered. Bedrock is located beneath the alluvial and its depth varies at the site and outcrops at some specific locations. The encountered alluvium is mainly medium-high plasticity, dark brown medium stiff clay, occasionally sand and gravel. The encountered sandstone, mudstone interlayered bedrock units have low rock quality designation, it is weathered and fractured. Following the completion of boreholes, ground water within two of the boreholes was monitored by piezometers. According to the recordings, groundwater table is quite variable and is located 1.0m to 10.0m below the ground surface. Soil stratigraphy generated from the soundings is given in Figure 1.

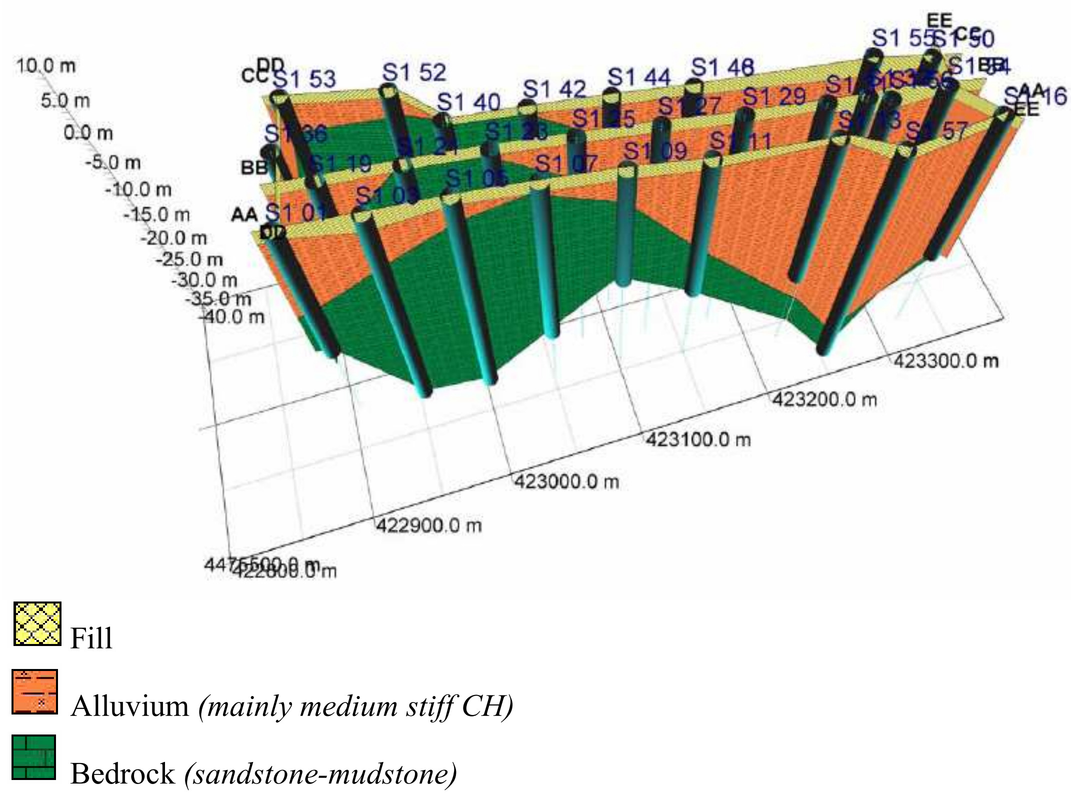

Figure 1. Soil stratigraphy

3 IN-SITU TESTS

In-situ tests including CPT, SCPT, DMT and SDMT are performed at the site. A total of twenty-four (24) CPT's, five (5) DMT's were performed. Tests were continued until sandstone, mudstone bedrock or where more advancement was not possible or to a maximum depth of 30.0 m. Consequently, the test depths achieved in testing varied between 3.8m to 30.0m.

4 OBTAINED DATA

4.1 *Data obtained from CPT's*

Simple electrical cones were utilized during the site investigations. Simple cones have built-in load cells that record the end bearing stress q_c, and friction sleeve stress, f_s. Readings are obtained at every 2.0cm depth. In seismic tests to measure shear wave velocities special seismic cones were employed, SCPT.

4.2 *Data obtained from DMT's*

Traditional Marchetti's flat dilatometer tests (DMT) were executed at the site. Tests were performed to measure the "lift-off", A-pressure and the "full expansion", B-pressure every 20 cm. Similarly, shear wave velocities are measured using the seismic DMT (SDMT).

5 SUBSOIL MODELLING

5.1 *Subsoil modeling using CPT's*

Soil classification using the CPT data was performed according to the simplified Soil Classification Chart for Standard Electronic Friction Cone (Robertson and Campanella, 1985). In order to estimate internal friction angle, the average empirical relationship is utilized which is proposed by Robertson and Campanella (1983). Estimates of s_u for the clay formations from CPT using CPT results generally employ an equation of the following form;

$$s_u = \frac{q_c - \sigma_{vo}}{N_k} \tag{1}$$

where σ_{vo} is the total overburden stress and N_k is the cone factor. Undrained shear strength values are estimated with an N_k value of 15. Constrained modulus values are calculated according to the following formula (Robertson and Campanella, 1988);

$$M = \alpha q_c \tag{2}$$

where the factor α is generally recommended in the range of 1.5 to 4.0 and is taken as $\alpha = 3$ in the modeling.

5.2 *Subsoil modeling using DMT's*

Soil classification using the DMT data was performed according to the procedure utilizing material index, I_D defined by Marchetti (1980). Internal friction angle, ϕ was obtained by the following equation (Marchetti, 1997);

$$\phi = 28° + 14.6° \log K_D - 2.1° \log^2 K_D \qquad (3)$$

where K_D is horizontal stress parameter. K_D provides the basis for several soil parameter correlations and is a key result of the dilatometer test. ϕ from Equation 3 is intended to be not the "most likely" estimate of ϕ, but a lower bound value, typical entity of the underestimation believed to be 2° to 4°. The horizontal stress index K_D is defined as follows (Marchetti 1980, Jamiolkowski et al. 1988);

$$K_D = \frac{p_0 - u_0}{\sigma'_{v0}} \qquad (4)$$

where σ'_{vo} is the pre-insertion in situ overburden stress. The correlation utilized for determining s_u from DMT (Marchetti, 1980) is the following;

$$s_u = 0.22\sigma'_{v0}(0.5K_D)^{1.25} \qquad (5)$$

Constrained modulus values are calculated according to the following formula (Marchetti et al., 2001);

$$M = R_M E_D \qquad (6)$$

$$E_D = 34.7(p_1 - p_0) \qquad (7)$$

where R_M is calculated with respect to K_D and I_D.

6 COMPARISON OF RESULTS

6.1 *Soil classification*

Grain size analyses and Atterberg's limits tests were performed on 128 samples retrieved from all boreholes (Zemin Etüd ve Tasarım A.Ş., 2008). Approximatly three or four specimen were taken within each borehole at varying depths. 25 percent of the specimen were found to be coarse grained according to USCS, Unified Soil Classification System and the remaining 75 per cent was found to be fine grained. Within the fine grained specimen, 99 per cent was found to be clay.

According to the soil classification model, the site is typically alluvium mainly composed of coarse grained soil (sands) within a fine grained soil (clay and silt). When CPT soil classification and DMT soil classification is compared, both classifications are able to identify the different coarse grained units from fine grained units coherently. However, DMT defines silt units within the clay units. This is due to the fact that I_D, metarial index used for DMT soil classification, sometimes misdescribes silt as clay and vice versa, therefore a presence of clay-sand both would generally be described by I_D as silt (Marchetti et al., 2001).

6.2 *Internal friction angle*

Internal friction angle, ϕ of coarse grained deposits derived from all CPT and DMT data is combined and provided in Figure 2. Generally, the estimations were found to be coherent. However, the minor differences could be attributed to the ϕ values derived from DMT results, is a "lower bound" value, typical entity of the underestimation believed to be 2° to 4°(Marchetti, 1997). The chart for derivation of ϕ of from CPT results tends to predict conservatively low friction angles as well (Robertson and Campanella, 1988)

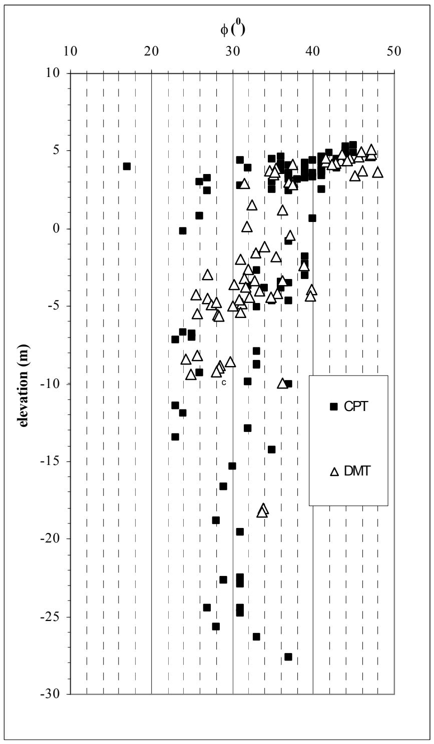

Figure 2. Variation of ınternal friction angle with elevation

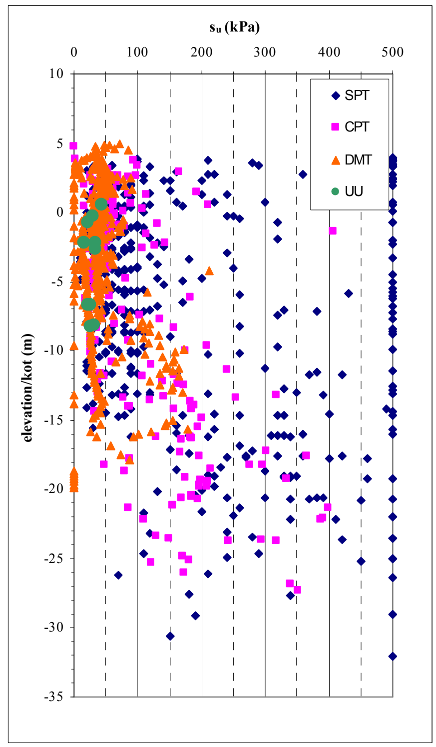

Figure 3. Variation of undrained shear strength with elevation

6.3 *Undrained shear strength*

Undrained shear strength, s_u of fine grained deposits is also obtained from CPT and DMT. Standard penetration tests (SPT) were performed within 38 boreholes. s_u is estimated from these SPT values according to the relationship provided by McGregor et. al. (1998). Results of undrained triaxial compression tests (UU) are also included in the comparison. s_u derived from CPT, DMT, SPT and UU data is combined and provided in Figure 3.

The values obtained from CPT's were more diverse and some data points are higher in value relative to the values derived from the DMT. SPT usually overestimates undrained shear strength and therefore is not dependable. On the other hand s_u values estimated from DMT were in good agreement with the results of triaxial UU testing.

6.4 *Constrained Modulus*

The values obtained from DMT's were more diverse and some data points are higher in value relative to the values derived from the CPT, see Figure 4. However, mainly the estimations were found to be coherent. The reasons for relatively low constrained modulus values derived from CPT results, could be attributed to the assumption of constrained modulus factor, α as equal to 3.

6.5 *Shear Wave Velocities*

Shear wave velocities were measured both by SCPT and SDMT. In addition, MASW-MAM multichannel surface wave analysis- microtremor array measurements were also performed. The results are presented in Figure 5. Generally, measurements with different techniques were found to be coherent. On the other hand Vs values from SCPT are slightly lower than SDMT. This deviation probably is due to the fact that SCPT test is performed using single and SDMT tests are performed using double receivers.

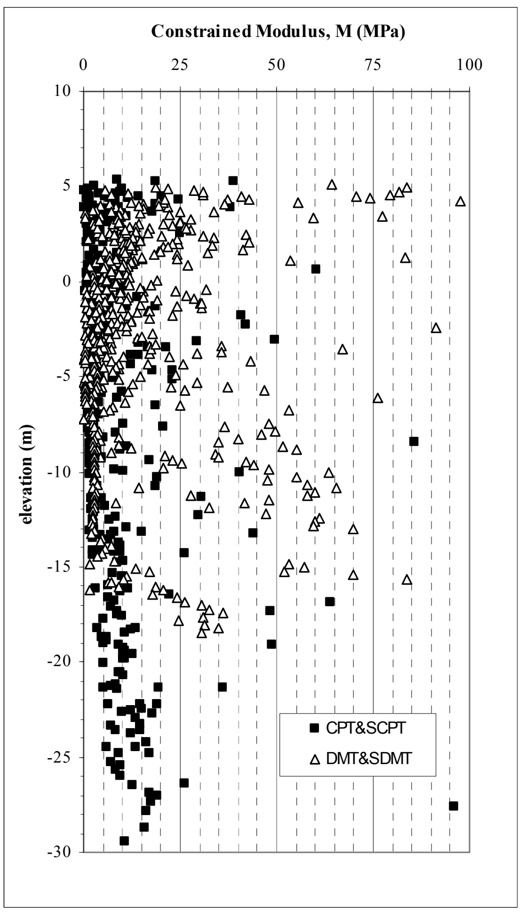

Figure 4. Variation of Constrained Modulus with elevation

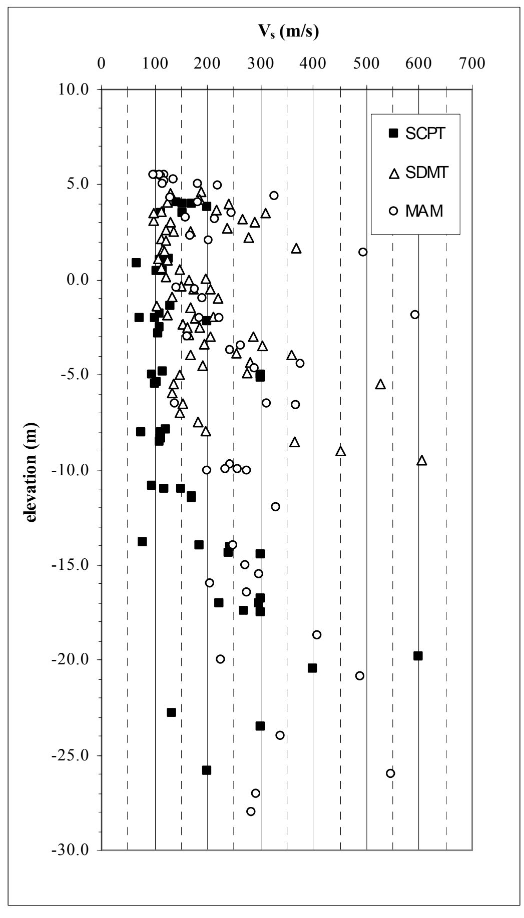

Figure 5. Variation of Shear Wave Velocity with elevation

6.6 *Comparison of close investigation points*

Specific CPT's are compared with specific DMT's which are close to each other. In these comparisons, soil classification, undrained shear strength and internal friction angle values were also evaluated.

Generally, soil classification of pairs was coherent. However, as mentioned above, dilatometer classifies some of the fine grained soils as silts which are found to be clay by laboratory tests. Undrained shear strength values were generally found to be coherent in soft clay units, however the CPT tends to give higher s_u values in stiffer units (s_u > 100kPa). The internal friction angle, calculated from CPT, was higher or close to the highest values of values calculated from DMT. In generally, the comparison of the results of specific points was in good agreement with the results of whole site.

7 CONCLUSIONS AND RECOMMENDATIONS

In situ testing is rapidly emerging as a viable alternative to the traditional approach for obtaining geotechnical parameters required in soil modelling. The site investigation for a hot reverse mill project in Gemlik included, dilatometer tests (DMT, SDMT), and cone penetration tests (CPT, SCPT). The soil classification and soil parameters predicted by both in-situ methods for the whole site and for eleven closely located pairs of investigation points were compared.

When CPT soil classification and DMT soil classification is compared, mainly both classifications are able to identify the different coarse grained units from fine grained units coherently. However, DMT sometimes misdescribes clays as silt. According to the grain size analyses and Atterberg's limits tests that were performed. 25 percent of the specimen were found to be coarse grained according to USCS, and the remaining 75 per cent were found to be fine grained. Within the fine grained specimens, 99 per cent were found to be clay. If a clay for some reason, behaves "more rigidly" than most clays, such clay will likely to be interpreted by I_D as silt, in DMT.

Subsoil models of close investigation pairs were also investigated. Generally, soil classification of pairs were coherent and the results were consistent with the results of the complete site modelling.

Internal friction angle, ϕ values derived for sands from all CPT and DMT data were combined and compared. Generally, the estimations were found to be coherent. However, the minor differences could be attributed to the ϕ values derived from DMT results is a "lower bound" value. The chart for derivation of ϕ of from CPT results tends to predict conservatively low friction angles as well (Robertson and Campanella, 1988).

Estimates of s_u from CPT, using cone bearing results were performed according to the equation recommended by Robertson and Campanella, 1988. The cone factor, N_k in the predictions was assummed as 15. The correlation by Marchetti, 1980 was utilized in the estimations of s_u from DMT. The values obtained from CPT's are more diverse and some of data points are higher in value relative to the values derived from DMT data probably indicating that more proper N_K value for deposits are higher than 15.

8 ACKNOWLEDGEMENT

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