Using Combination of SPT, DMT and CPT to Estimate Geotechnical Model for a Special Project in Turkey

Figen ORHUN ÖNAL
GE, M.Sc., Site Works Manager, Zemin Etud ve Tasarım A.Ş., Istanbul, figen.orhun@zetas.com.tr

Gülçin ÖZMEN
GE, M.Sc., Laboratory Manager, Zemin Etud ve Tasarım A.Ş.., Istanbul, gulcin.ozmen@zetas.com.tr

Keywords: DMT, CPT, SCPT, SPT, soil parameters, geotechnical model.

ABSTRACT: An important project is selected as subject site of this paper. Project site is located at Gemlik District, Bursa City. The subject site comprises some special factory structures and heavy machinery foundations. Within the scope of soil investigation, boreholes were drilled; Standard Penetration Test (SPT) was performed. In addition to drilling Cone Penetration Test (CPT), Seismic Cone Penetration Test (SCPT), Marchetti Dilatometer Test (DMT) and Seismic Dilatometer Test (SDMT) were carried out. This paper discusses the combine usage of SPT, DMT and CPT results to estimate soil parameters such as undrained shear strength (s_u), friction angle (Φ) and shear wave velocities (v_s). This study concludes that all of SPT, DMT and CPT results were compatible with each other to provide subsoil model for the investigation area. All tests were particularly helpful in identifying weak zones and sand pockets.

1 INTRODUCTION

Marchetti Dilatometer test (DMT), Cone Penetration Test (CPT) and Standard Penetration Test (SPT) are most common in-situ tests used in soil investigations. DMT is the latest one; the early dilatometer test (DMT) equipment was developed by Dr. Silvano Marchetti in 1974 at the L'Aquila University in Italy. The early Cone Penetration Test (CPT) equipment was developed at the Dutch Laboratory for Soil Mechanics in Delft in the 1950's to investigate soft soils. The Standard Penetration Test (SPT) is the initial one, it was introduced from the beginning of 1920's, and a special paper was presented by Terzaghi about SPT to the 7th Texas Conference on Soil Mechanics and Foundation Engineering in 1947.

Important soil parameters such as undrained shear strength values (s_u), internal friction angles (Φ), and relative density values (Dr), deformation modules (Es), etc. can be estimated by SPT, CPT and DMT data according to different approaches. Besides those parameters shear wave velocities (v_s) and pressure wave velocities (v_p) can be obtained from Seismic Cone Penetration Test (SCPT) and Seismic Dilatometer Test (SDMT). CPT and DMT are both special tests for sandy and clayey soft soils; however SPT is suitable for all kind of soils. Determination of dynamic parameters is quite essential, especially in countries which have significant seismic activities such as Turkey.

The subject area is located at Bursa City Gemlik District. The subsoil investigations were performed towards the design of the proposed hot strip mill structures and heavy machinery foundations by Zemin Etüd ve Tasarım A.Ş. (www.zeminetudtasarim.com.tr). Structures have two halls 30.0mx420.0m in dimension, a hall 20.0mx230.0m in dimension and a structure 50.0mx70.0m in dimension. Within the structures there are special machinery pits and foundations and they designed separately. Structures designed as steel and they have two storey. Within the scope of soil investigation; borehole drilling, standard penetration test, cone penetration test, seismic cone penetration test, dilatometer test and seismic dilatometer test were performed. In this paper all SPT, DMT-SDMT and CPT-SCPT results were evaluated and compared for subject site.

2 METHODOLOGY OF SPT, CPT AND DMT

2.1. Standard Penetration Test (SPT)

Standard Penetration Test (SPT) is performed in soils with regular intervals of 1.5m using rope and automatic hammer release systems in accordance with ASTM D-1586. Obtained SPT- N values during the course of boreholes are corrected for overburden stress (C_N), energy ratio (C_E), rod length (C_R), borehole diameter (C_B) and sampling method (C_S) is given by the following equation;

$$(N)_{60} = N.C_E.C_B.C_R.C_S \quad (1)$$

$$(N_1)_{60} = N.C_N.C_E.C_B.C_R.C_S \quad (2)$$

For fine grained soils; below correlation (Figure - 1) was utilized to approach the undrained shear strength (s_u). However, the accuracy of the chart is rather poor.

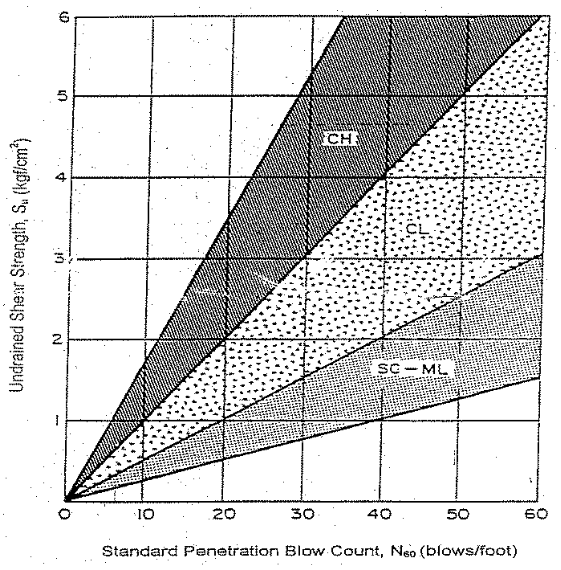


Figure – 1 Relationship between standard penetration blow count, N and undrained shear strength (s_u), (after Sowers, 1979)

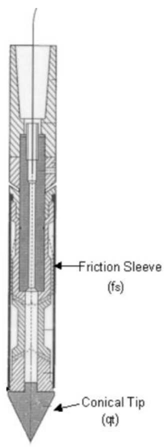
Estimates of friction angle (Φ) from SPT using N values generally employ the below equation (Ohsaki et al. 1959).

$$\Phi = (20N)^{0.5} + 15 \quad (3)$$

There are many other empirical correlations had been developed in past.

2.2. Cone Penetration Test (CPT)

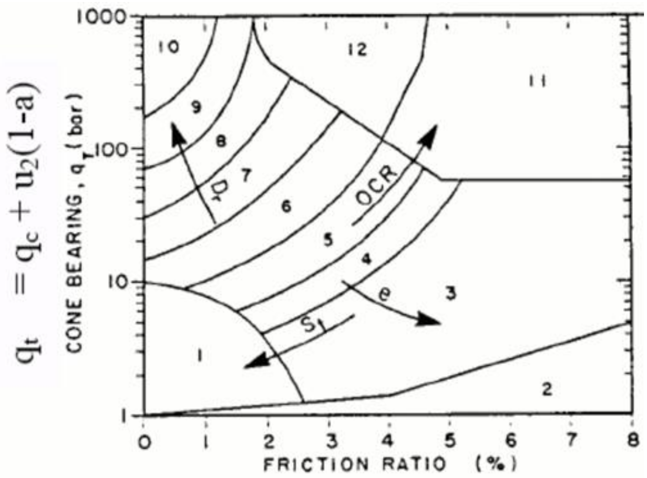
CPT is one of the most used and accepted in soil methods for soil investigation worldwide. The test method consists of pushing the test cone, with the tip facing down, into the ground at a controlled rate (controlled between 1.5 -2.5 cm/s accepted).



Electrical cones were used for 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 (v_s) special seismic cones were employed, SCPT.

Figure – 2 CPT equipment and control unit

Soil classification using the CPT data was performed according to the simplified soil classification chart for standard electronic friction cone (Robertson and Campanella, 1985).



Zone	q_c/N	Soil Behaviour Type
1.	2	Sensitive fine-grained soil
2.	1	Organic soil
3.	1	Clay
4.	1.5	Silty clay to clay
5.	2	Clayey silt to silty clay
6.	2.5	Sandy silt to clayey silt
7.	3	Silty sand to sandy silt
8.	4	Sand to silty sand
9.	5	Sand
10.	6	Sand to gravelly sand
11.	1	Very stiff fine-grained soil
12.	2	Overconsolidated or cemented sand to clayey sand

Figure-3Simplifies soil classification chart for standard electronic friction cone;(Robertson, 1985)

In order to estimate internal friction angle (Φ), the average empirical relationship is utilized which is proposed by Robertson and Campanella (1983).

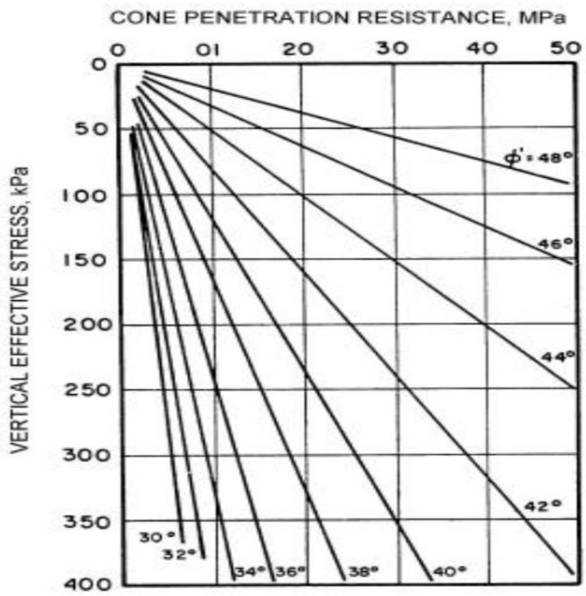


Figure – 4 Proposed correlation between cone bearing and peak friction angle (Robertson and Campanella, 1983)

Estimates of s_u for the clay formations from unit tip resistance (q_c), total overburden stress (σ_{vo}) and cone factor (N_k) is given by the following equation;

$$s_u = \frac{q_c - \sigma_{vo}}{N_k} \qquad (4)$$

2.3. Marchetti Dilatometer Test (DMT)

Marchetti Dilatometer (DMT) provides a simple method for the rapid, accurate, and economical in-situ determination of important soil parameters. The blade is constructed of high-strength stainless steel. Normally the blade is advancing by pushing from a cone penetrometer rig. It may also be pushed with the hydraulic capability of a drill rig. The test starts by inserting the dilatometer blade into the ground. Gas pressure supplied through tubing from a control unit at the surface is then used to expand a flexible membrane on the face of the blade.

The operator determines the A-pressure required initiating movement of the membrane and the B-pressure required moving its centre 1 mm into the soil. Typically the operator performs this simple test at depth intervals of 20 cm. Similarly, shear wave velocities are measured using the seismic DMT (SDMT). Dilatometer modulus (E_D), material index (I_D), horizontal stress index (K_D), vertical drained constrained modulus (M), internal friction angle (ϕ), undrained shear strength (s_u), over consolidation ratio (OCR), coefficient of earth pressure at rest K_0 values are determined.

Figure – 5 Marchetti Dilatometer blade and control unit.

Internal friction angle (ϕ) was obtained by the following equation (Marchetti, 1997);

$$\phi = 28° + 14.6° \log K_D - 2.1° \log^2 K_D \qquad (5)$$

The correlation utilized for determining s_u from DMT (Marchetti, 1980) is the following;

$$s_u = 0.22\sigma'_{v0}(0.5K_D)^{1.25} \qquad (6)$$

The horizontal stress index K_D is defined as follows (Marchetti 1980, Jamiolkowski et al. 1988);

$$K_D = \frac{p_0 - u_0}{\sigma'_{v0}} \qquad (7)$$

3 SITE INVESTIGATIONS

To determine the subsoil conditions in subject site, rotary boreholes were executed in 2008. Thirty-eight (38) boreholes having a total depth of approximately 850.0m were performed. In addition to boreholes; twenty-seven (27) CPT, six (6) SCPT, three (3) DMT and six (6) SDMT were performed. Tests were performed in clayey, sandy alluvial unit and continued until sandstone, mudstone bedrock or where more advancement was not possible or to a maximum depth of 30.0 m. The test depths achieved in testing varied between 3.8m to 30.0m.

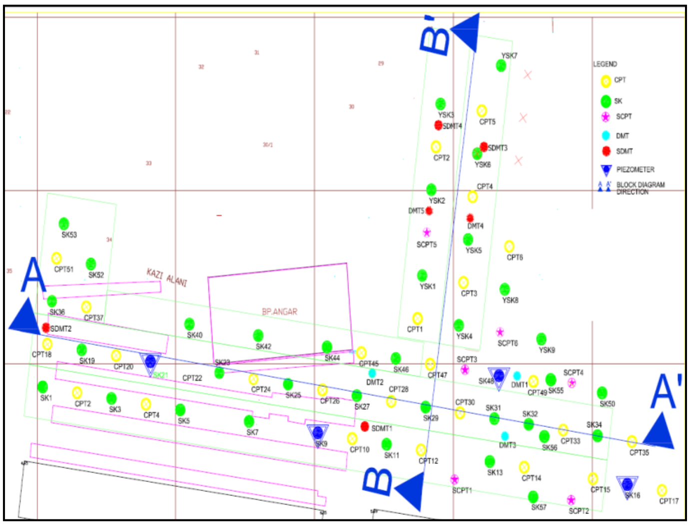


Figure 6 – Soil Investigations Layout Plan

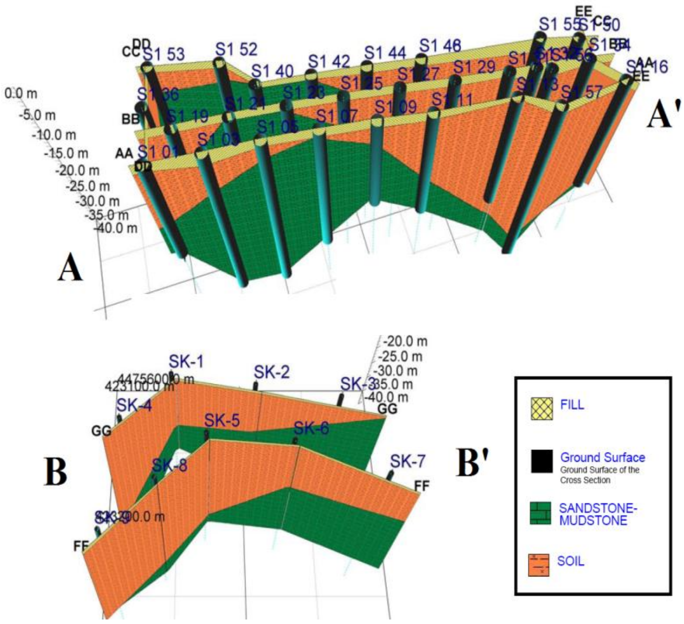


Figure 7 – A-A' and B-B' Block Diagram according to boreholes

4 LOCAL GEOLOGY AND SEISMICITY OF THE SUBJECT SITE

4.1. Local Geology

Subject site is mainly covered with asphalt and 2.0m thick controlled filled underneath asphalt layer. Following this alluvium layer having varying thickness was encountered. Following this layer bedrock belong to Kurbandağı Formation exists. Bedrock depth varies and outcrops close to western of the site. Encountered subsoil is mainly composed of medium-high plasticity, medium stiff clay, occasionally sand and dark brown, dark grey, black, moist-wet, occasionally gravel. The encountered sandstone, mudstone interlayed bedrock units has poor rock quality designation, weathered, fractured and coated with FeO and MnO.

4.2. Seismicity Of The Subject Site

Subject site is located in Bursa. Bursa City is located in the Marmara Region; therefore the seismicity of the city must be studied under the scope of Marmara Region seismicity. Locally Bursa, in the general sense Marmara Region is located within the 1st degree (the first highest risk) earthquake zone in the Turkey Earthquake Zoning Map. Seismicity of the Marmara region is relatively very high as indicated by both the historical and recent (instrumental period) devastative earthquakes since it is located at the Alpin Orogeneous Belt and is restricted in a seismically very high active region. The North Anatolian Fault and the West Anatolia Aegean Graben Systems are observed to be seismically quite active in the 20th century.

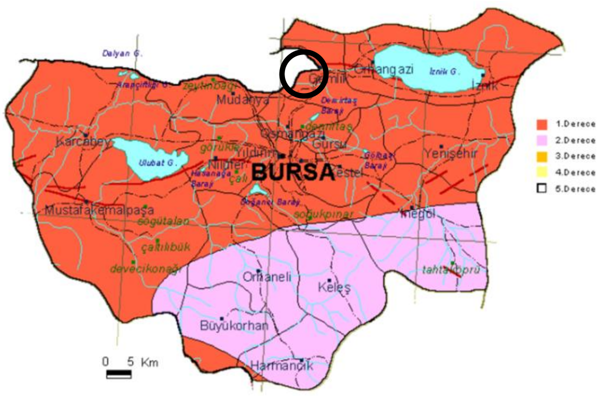


Figure 8 - Earthquake Zoning Map of Bursa (Ministry of Public Works and Settlement of the Republic of Turkey, 2007)

5 COMPARISON OF TEST RESULTS

5.1. Soil Classification

According to grain size analyses and Atterberg's limits tests approximately 25 percent of the specimen was found to be coarse grained and 75 percent was found to be fine grained. Within the fine grained specimen, 99 percent was found to be clay.

Both DMT and CPT were provided consistent classifications. They are able to identify the different coarse grained units from fine grained units coherently.

5.2. Internal friction angle

Internal friction angle (ϕ) of coarse grained deposits derived from all SPT, CPT and DMT data is combined and provided in Figure 9. Standard penetration tests (SPT) were performed within all performed boreholes. Internal friction angle (ϕ) is estimated from these SPT N values according to the relationship provided by H&T (1996). Generally, the estimations were found to be coherent. However, the minor differences could be attributed to the ϕ values.

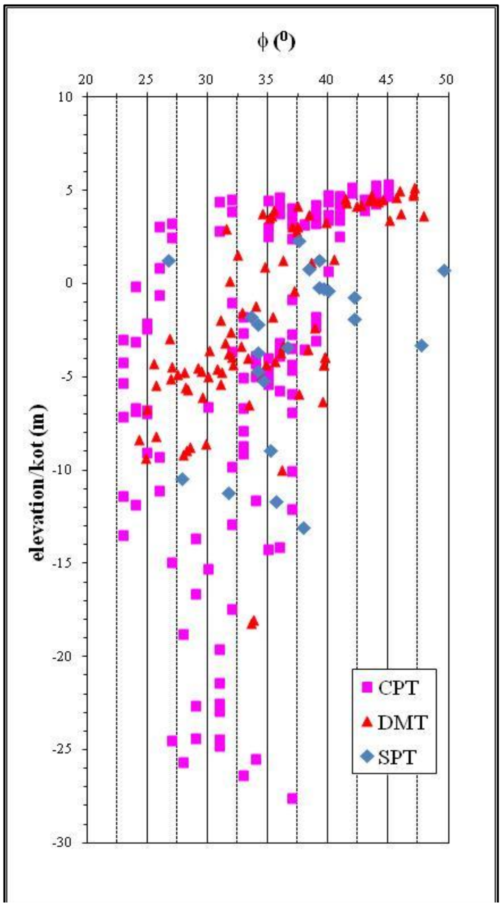


Figure 9 – Variation of internal friction angle with elevation

Table 1- Summary of Internal Friction Angle (ϕ)

Internal Friction Angle (ϕ)		
CPT	***DMT***	***SPT***
Minimum: 23^0	Minimum: 24^0	Minimum: 26^0
Maximum 45^0	Maximum: 48^0	Maximum: 50^0

5.3. Undrained shear strength (s_u)

Undrained shear strength (s_u) of fine grained deposits is also obtained from CPT and DMT. Undrained shear strength (s_u) is estimated from SPT values according to the relationship provided by McGregor et. al.(1998). Both SPT and CPT were provided consisted values and some data points are higher in value relative to the values derived from the DMT

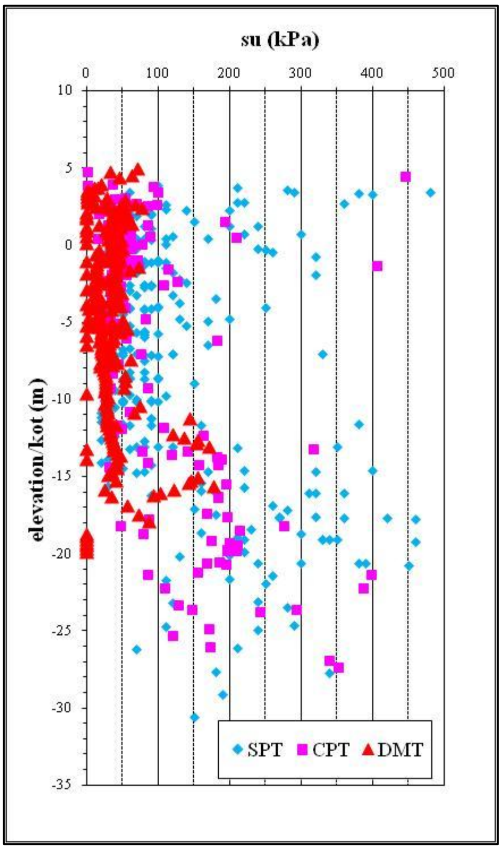


Figure 10 – Variation of undrained shear strength with elevation

Table2-Summary of Undrained Shear Strength (s_u)

Undrained Shear Strength (su) (kPa)		
CPT	***DMT***	***SPT***
Minimum: 0	Minimum: 0	Minimum: 10
Maximum: 450	Maximum: 178	Maximum: 480

5.4. Shear Wave Velocities (v_s)

Both SCPT and SDMT tests were performed to measure Shear wave velocities (v_s) in subject site. The results are presented in Figure 5. Generally, measurements with different techniques were found to be coherent. Average v_s value obtained from SCPT is 195 m/s and the average v_s value obtained from SDMT is 200 m/s. According to this case SCPT are slightly lower than SDMT.

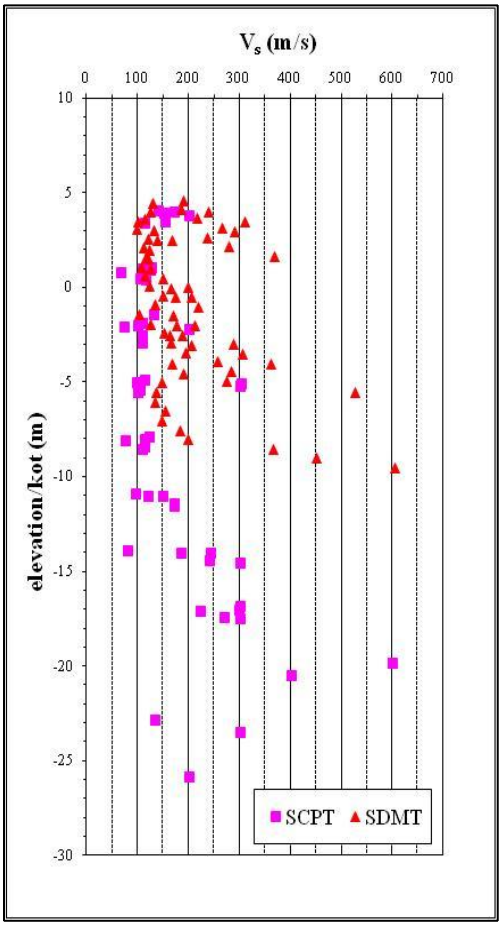


Figure 11 – Variation of shear wave velocities with elevation

Table 3- Summary of Shear Wave Velocities (v_s)

Shear Wave Velocities (vs) (m/s)	
CPT	***DMT***
Minimum: 65	Minimum: 95
Maximum: 600	Maximum: 605

6 EVALUATIONS AND CONCLUSIONS

In the scope of subject site SPT, CPT and DMT tests were performed; tests results are summarized and compared within the paper.

Both DMT and CPT were provided consisted classifications with grain size analyses and Atterberg's limits tests. They are able to identify the different coarse grained units from fine grained units coherently.

Internal friction angle (ϕ) values acquired for sands from all SPT, CPT and DMT data were combined and compared. Internal friction angle estimations were generally found to be coherent. However, the minor differences could be attributed to the ϕ values. Minimum values are varying between 23^0 and 26^0, maximum values are varying between 45^0 and 50^0. Slightly higher internal friction angles were estimated by SPT N values compared to DMT and CPT.

Undrained Shear Strength (s_u) values acquired from SPT and CPT are consistent, but some data points are higher in value relative to the values derived from the DMT. Average su value obtained from all tests approximately 50 kPa. Minimum value is approximately 10 kPa for all tests and maximum value is approximately 480 kPa for SPT and CPT, but 178 kPa for DMT.

Average shear wave velocity (v_s) values obtained from SCPT is 195m/s and the average v_s value obtained from SDMT is 200m/s. According to this case minimum v_s value obtained from SCPT is slightly lower than SDMT.

In conclusion; when the values were compared with each other, it's noticed that their intensity ranges were coherent except the minor differences. For data diversity to perform CPT and DMT addition to drilling is very advantageous but under limited conditions and time schedules CPT and DMT gives reliable results for both fine grained and coarse grained soil conditions.

7 REFERENCES

Zemin Etüd ve Tasarım A.Ş., 2008, *Borusan Mühendislik Hot Reverse Mill Project Subsoil Investigations and Subsoil Modelling Preliminary Report-Phase I*, Bursa, Turkey.

Aykin, K. 2009, *Comparison of Soil Modelling Using CPT and DMT-A Case Study*, M.S. Thesis, Bogazici University, Civil Engineering Istanbul, Turkey.

Jamiolkowski, M., V. Ghionna, R. Lancellotta and E. Pasqualini, 1988, *New Correlations of Penetration Tests for Design Practice*. Proc. ISOPT-1, Orlando, FL, Vol. 1, pp. 263-296.

Marchetti S., 1980, *In Situ Tests by Flat Dilatometer*. ASCE Journal GED, Vol. 106, No. GT3, Mar., 299-321.

Marchetti S., 1997, *The Flat Dilatometer: Design Applications*. Proc. Third International Geotechnical Engineering Conference, Keynote lecture, Cairo University, Jan., pp. 421-448.

Robertson, P.K. and R.G. Campanella, 1983, Interpretation of Cone Penetration Tests – Part I (Sand), *Canadian Geotechnical Journal*, Vol. 20, No. 4, pp. 718-733.

Robertson, P.K., and R.G. Campanella, 1985, Evaluation of Liquefaction Potential of Sands Using the CPT, *Journal of Geotechnical Division*, ASCE, Vol. III, No. 3, Mar., pp. 384-407.