Missouri University of Science and Technology
Scholars' Mine

International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

2010 - Fifth International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

26 May 2010, 4:45 pm - 6:45 pm

Comparison of Dynamic Soil Modelling Using SCPT, SDMT and SASW

Kayhan Aykin
Zemin Etud ve Tasarim A.S., Turkey

Onder Akcakal
Zemin Etud ve Tasarim A.S., Turkey

H. Turan Durgunoglu
Bogazici University, Turkey

Ozer Akbal
Borusan Eng. Corp., Turkey

Fifth International Conference on
Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
and Symposium in Honor of Professor I.M. Idriss
May 24-29, 2010 • San Diego, California

COMPARISON OF DYNAMIC SOIL MODELLING USING SCPT, SDMT AND SASW

Kayhan Aykin
Project Engineer
Zemin Etud ve Tasarim A.S.
Umraniye, Istanbul, Turkey

Onder Akcakal
Project Engineer
Zemin Etud ve Tasarim A.S.
Umraniye, Istanbul, Turkey

H.Turan Durgunoglu
P.E., Ph.D., F. ASCE,
Professor Emeritus
Bogazici University, Istanbul

Ozer Akbal
P.E. General Manager
Borusan Eng. Corp.
Istanbul, Turkey

ABSTRACT

A site investigation campaign using cone penetration test (CPT), dilatometer test (DMT) are carried on alluvial deposits at a site located at Gemlik, Turkey towards the design of a newly planned hot reverse mill structure within the existing Borçelik steel factory. Site is located at the south of North Anatolian Fault that is sheared during 1999 Kocaeli Earthquake. In addition, the site is under the influence zone of another fault line going through the Gemlik Bay. Therefore, prediction of the behaviour of saturated alluvial deposits under a major expected design earthquake of the planned structures is the prime importance in terms of safety and meeting the performance criteria of the subject structures.Seismic cones (SCPT) and dilatometers (SDMT) together with spectral analysis of surface waves (SASW) are also carried out in order to obtain shear wave velocity profile for seismic modelling. Data obtain from CPT, DMT, SCPT, SDMT and SASW is used for subsoil geotechnical modeling. Soil models are also supported with SPT data and laboratory test results. Obtained Vs profiles with various techniques are compared for whole site models and between closely located investigation pairs.

INTRODUCTION

The interpretations 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 the soil disturbance and limited number of tests draws more attention to the in-situ tests for design and analysis. In this paper dynamic soil modelling utilizing SCPT, SDMT and MASW is obtained for a seismically active site. The site is located within Gemlik Fault and approx. 40km's south of NAF that was activated during August 17, 1999 Kocaeli Earthquake (Olgun and et al., 2001) (Figure 1).

A newly planned hot reverse mill structure is to be constructed containing openings supported with deep permanent r.c. walls within alluvial deposits and foundations having very strict performance criteria interms of expected differential settlements during operations under the earthquake loads that may occur during the life time of the structure. Consequently, geotechnical modelling of subsoils both for static and under dynamic loadings to be used in displacement and safety predictions are the prime importance. Various structures within the hot reverse mill covers a distance over 400 meters along an longitudinal axis as shown in Figure 2. Due to nonhomogenity of the subsoil conditions and the extend of various structures over a long distance modern in-situ measurement techniques such as CPT, DMT and SASW in addition to classical borings and laboratory testing are employed for this specific project.

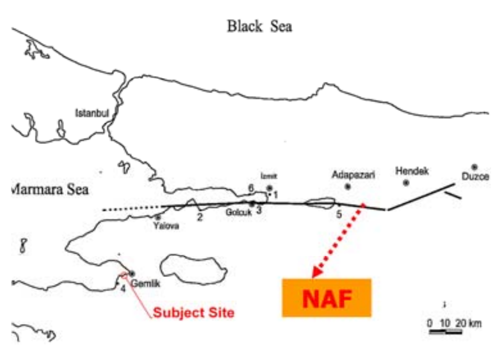

Figure 1. Location of the site and NAF

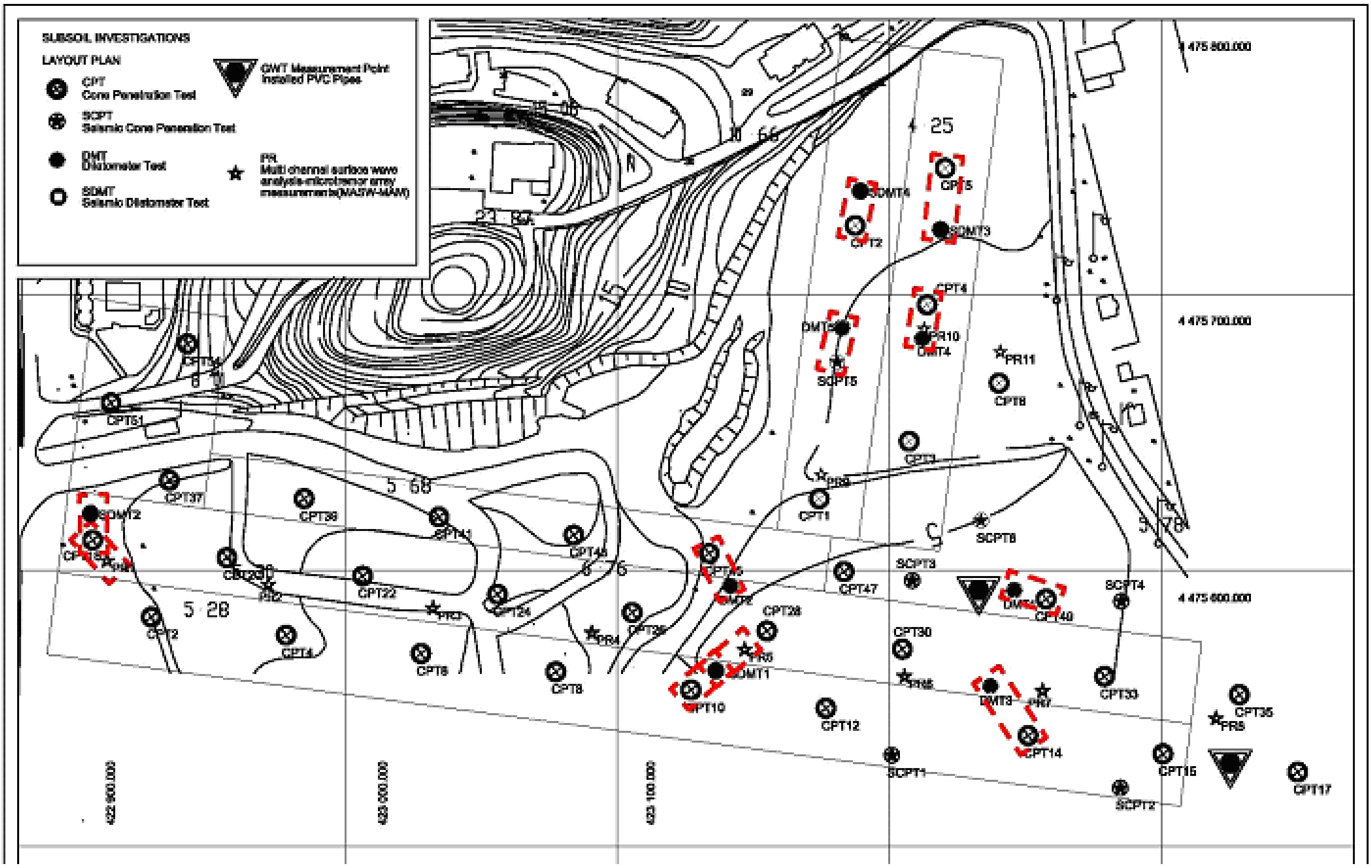

Figure 2 In-situ Measurements Layout Plan

It could be stated that the extensive utilization of CPT in Turkey, is more recent compared to Europe and USA 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 some how limited to university and state funded research projects (Emrem, 2000). On the other hand, utilization of Marchetti's (DMT) flat dilatometer is a rather recent in-situ testing method in Turkey (Zemin Etud ve Tasarim A.S., 2008).

The cone penetration test (CPT) provides two separate readings with depth, including; unit cone tip resistance (qc) and unit sleeve friction (fs), whereas the dilatometer (DMT) reflects different two readings compared to CPT, namely; the lift-off or contact pressure (p0) and expansion pressure (p1). Further advantage of utilizing cone and dilatometer testings are the fact that shear wave velocities and their variation with depth could easily be measured at specific investigation points utilizing seismic cones and seismic dilatometers, i.e. SCPT and SDPT. In this paper only comparison of soil modellings to be used for the purpose of prediction of subsoil behaviour under earthquake loadings will be presented. Further details of the pertinent data and the case study is presented by (Aykin, 2009).

LOCAL SUBSOIL CONDITIONS

Subject site at the planned hot reverse mill is mainly covered by approximately 2.0 m thick structural fill. Below the fill, alluvium layer having varying thickness and properties is encountered. Bedrock is located beneath the alluvium and its depth varies at the subject site and outcrops at some specific locations. Encountered alluvium is mainly medium-high plasticity, dark brown soft to medium stiff clay with occasional sand and gravel levels. The encountered sandstone, mudstone interlayered bedrock units has low rock quality designation, it is weathered and fractured. Following the completion of boreholes, ground water within two of the boreholes are monitored by piezometers. According to the recordings, groundwater table is quite variable depending on the point of investigation at the site and is located 1.0m to 10.0m from the ground surface.

IN-SITU TESTS

In-situ tests including CPT, SCPT, DMT and SDMT are performed at the site in addition to total number 29 borings. Total of twenty-four (24) CPT's, five (5) DMT's are 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 testings are varied between 3.8m to 30.0m.

OBTAINED DATA

Data obtained from CPT's

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

Data obtained from DMT's

Traditional Marchetti's flat dilatometer tests are also executed at the subject site. Tests performed to measure "lift-off", A-pressure and "full expansion", B-pressure at every 20 cm. Similarly, shear wave velocities are measured using SDMT (Marchetti and et al., 2008)

Data obtained from SASW's

In addition to SCPT and SDMT, multichannel surface wave analysis – microtremor array measurements SASW are performed for estimating variation of shear wave velocities with depth.

SOIL MODELLING

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 taken within each borehole at varying depths. 25 percent of the specimen were found to be coarse grained according to USCS and the remaining 75 percent was found to be fine grained. Within the fine grained specimen, 99 per cent was found to be clay. The distribution of plasticity index versus liquid limit of the specimens is given at Figure 3.

According to the soil classification model, the subject site is typical alluvium mainly composed of coarse grained (sands) and a fine grained (clay and silt) soils.

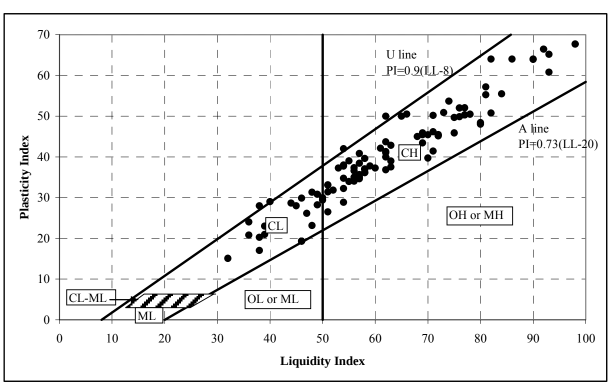

Figure 3. Plasticity chart

Soil classification using the cone penetration data was also performed according to the simplified Soil Classification Chart for Standard Electronic Friction Cone (Robertson and Campanella, 1985, 1988). Soil classification using the DMT data are performed according to the procedure utilizing material index, I_D defined by Marchetti (1980).

When CPT soil classification and DMT soil classification is compared, mainly both classifications are able to differ coarse grained soil units from fine grained coherently. However, DMT further 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 clay as silt and vice versa, therefore a presence of clay-sand both would generally be described by I_D as silt(Marchetti et al., 2001).

SPT Values

The SPT values are measured during borings according to ASTM D-1586. Blow counts are corrected for 60 percent energy and for overburden and corresponding $(N_1)_{60}$ values are determined (McGregor and Duncan, 1988). Variation of corrected blow count with depth within the alluvium is shown in Figure 4.

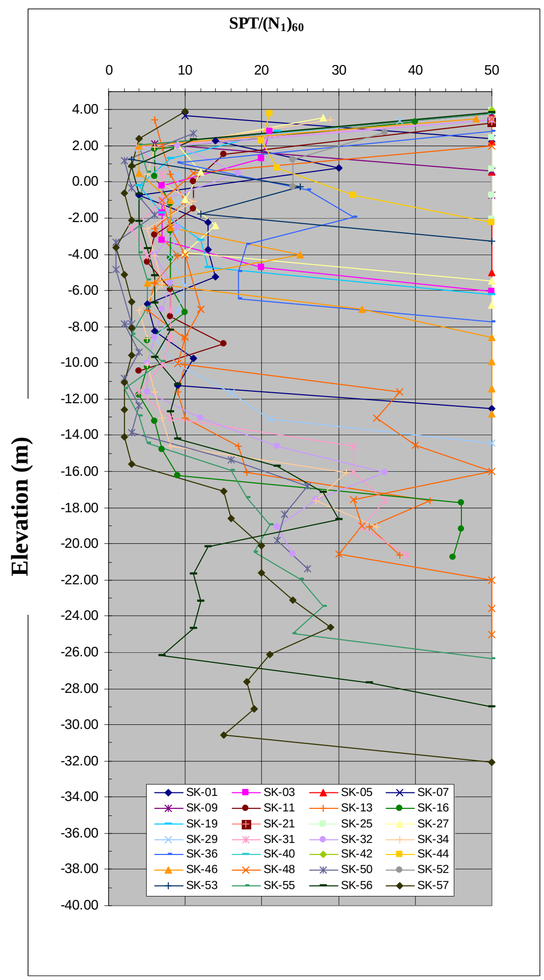

Figure 4. Variation of corrected blow count with depth

It is seen that at different locations thickness of the alluvium is as large as 20.0 meters and the $(N_1)_{60}$ values is generally between 2 and 10 indicating great potential risk of these alluvial layers in the performance of the planned structure under both static and earthquake loadings. Based on the potential seismicity of the site, it is determined that the sandy alluvial subsoil is likely to be liquefied according to the procedure described in (Youd and et al., 2001) using $(N_1)60$ values.

<u>Subsoil Modelling Using CPT's and SCPT's</u>

Twenty four CPT's without seismic measurements are performed within the scope of investigations. Additional six SCPT's are utilized for the purpose of Vs profiling.

In order to estimate internal friction angle of sands, the average empirical relationship is utilized which is proposed by Robertson and Campanella (1983). Estimates of su for the clay formations from CPT using cone bearing results generally employ an equation of the following form;

$$s_u = \frac{q_c - \sigma_{vo}}{N_k} \quad (1)$$

where σ_{vo} is the total normal stress and Nk is cone factor. Undrained shear strength values are estimated with an Nk value of 15 based on previous local practice. Shear wave velocities, Vs are measured using SCPT. The results are presented in Figures 5, 6, 7 and 8. It is seen that, undrained shear strength of clay deposits, su is low and generally between 20-80 kPa, As expected, friction angle of alluvial sand deposits are quite variable, ϕ = 25° - 40° depending on the relative density, Dr (%) =20 to 80.

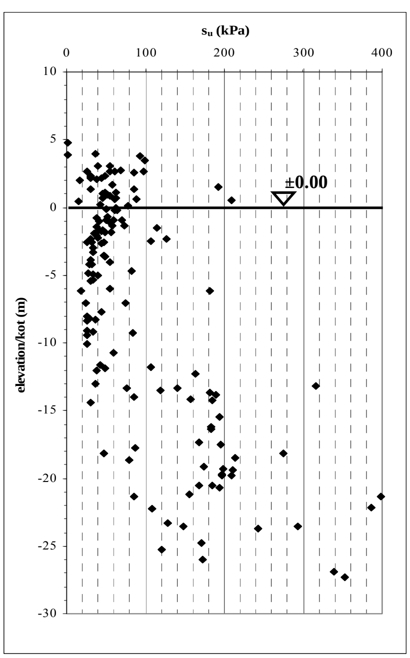

Figure 5. Variation of s_u values with depth

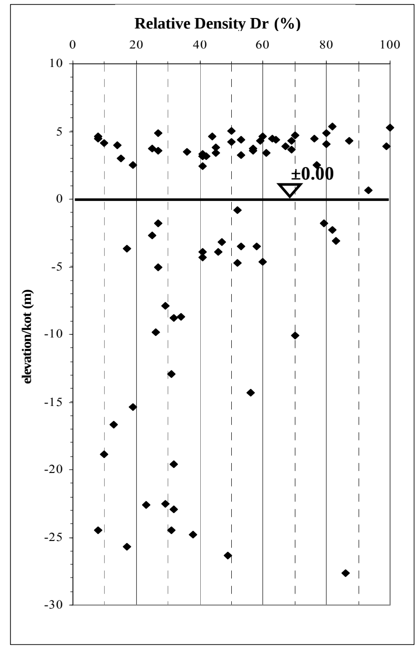

Figure 6. Variation of Dr values with depth

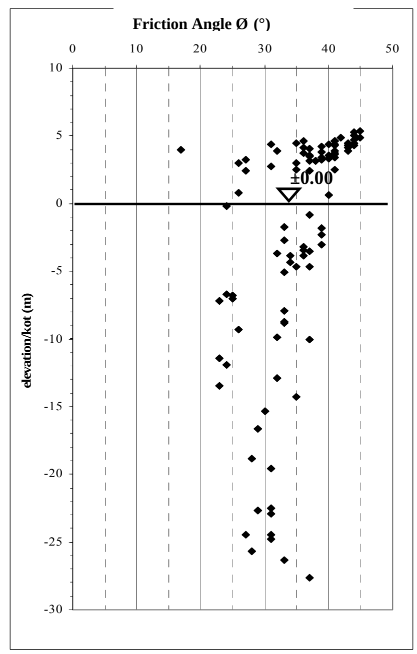

Figure 7. Variation of ϕ values with depth

As a result shear wave velocities of the alluvial deposits are quite variable and low, Vs = 80 – 180 m/sec (Figure 8). Again, subsoil modelling based on cone penetration test, have resulted factor of safeties against soil liquefaction lower than unity based on the CPT procedure described in (Youd et al., 2001).

<u>Subsoil Modelling Using DMT and SDMT's</u>

Five DMT's without seismic measurements are performed within the scope of geotechnical investigations using

Marchetti's flat dilatometer. Further, four additional SDMT's are performed for assesment of Vs profiling within the alluvial layer.

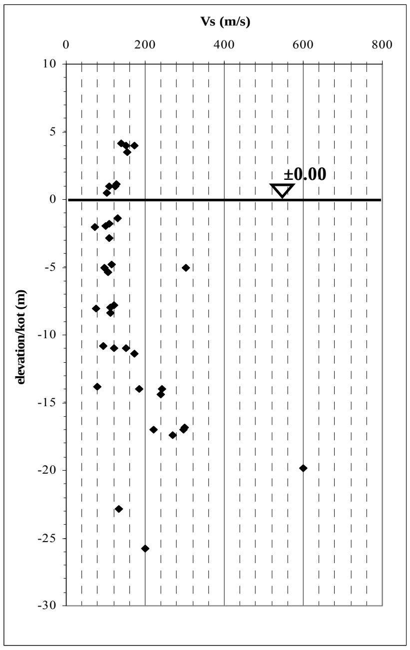

Figure 8. Variation of Vs values with depth

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

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

where K_D is horizontal stress index.

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

$$K_D = \frac{p_0 - u_0}{\sigma'_{v0}} \qquad (3)$$

where σ'_{v0} is the pre-insertion in situ overburden stress. The correlation utilized for determining su from DMT (Marchetti, 1980) is the following;

$$s_u = 0.22\sigma'_{v0}(0.5K_D)^{1.25} \qquad (4)$$

The results are presented in Figures 9, 10 and 11.

COMPARISON OF SHEAR WAVE VELOCITIES

Shear wave velocities are measured both by cone and dilatometer by means of SCPT and SDMT. In addition, MASW-MAM multichannel surface wave analysis-

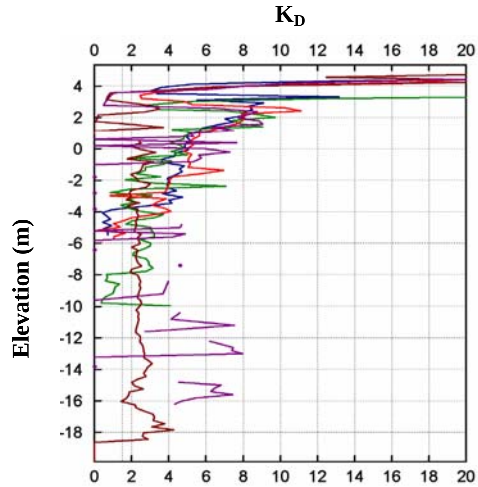

Figure 9. Variation of K_D values with depth

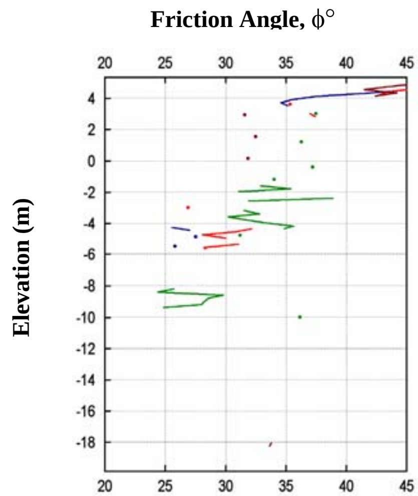

Figure 10. Variation of ϕ values with depth

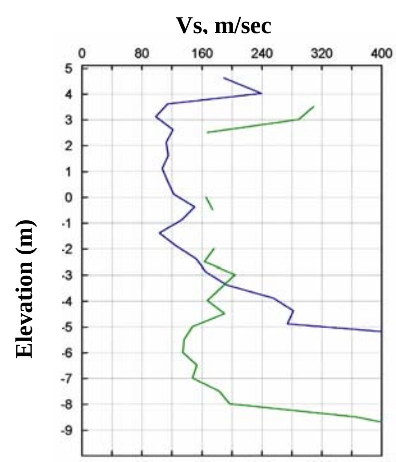

Figure 11. Variation of Vs values with depth

microtremor array measurements are also performed. The results are presented in Figure 12. Generally, measurements with different techniques are found to be comparable. 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.

In general, the comparison of the results of specific points are in good agreement with the results of whole site. An example of pair comparison of values obtained from SDMT and SASW is shown in Figure 13.

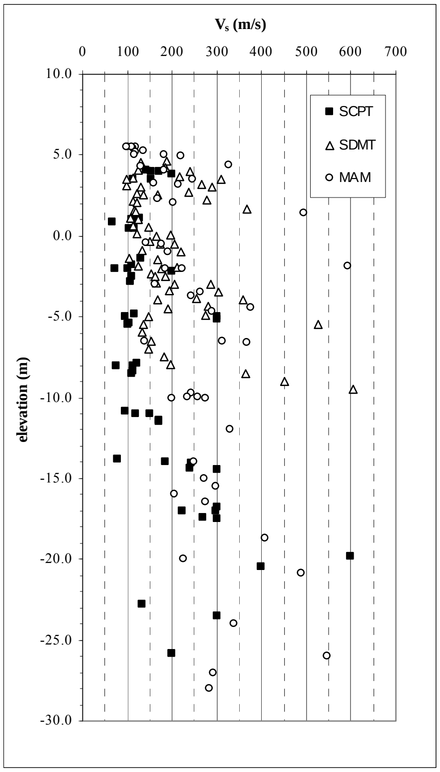

Figure 12. Variation of Vs Velocities with Depth

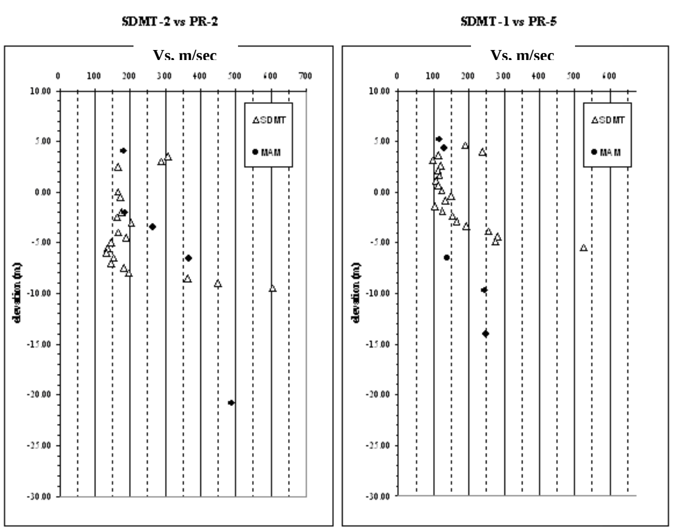

Figure 13. Comparison of Vs from SDMT vs SASW

CONCLUSIONS AND RECOMMENDATIONS

In situ testing is rapidly emerging as a viable alternative to the traditional approach of obtaining geotechnical parameters required in soil modelling in both static and earthquake loadings. The site investigation for hot reverse mill project in Gemlik a site seismically very active are included, dilatometer tests (DMT, SDMT), and cone penetration tests (CPT, SCPT) in addition for classical methods.

When CPT soil classification and DMT soil classification is compared, mainly both classifications are able to differ coarse grained units from fine grained units coherently. However, DMT sometimes misdescribes clays as silt. Based on 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 was found to be fine grained. Within the fine grained specimen, 99 per cent was 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.

Internal friction angle, ϕ derived for sands from all CPT and DMT data are also provided. Generally, the estimations are found to be comparable. 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 from CPT results tends to predict conservatively low friction angles as well (Robertson and Campanella, 1988).

Shear wave velocity, Vs profiling at the site for heterogenious alluvial deposits is obtained using three different methods namely, SCPT, SDMT and SASW. The comparison of the results have indicated good agreement.

ACKNOWLEDGEMENT

Authors would like to thank Ms. Gulcin Tezel, General Manager of Zemin Etud ve Tasarim A.S. for releasing the data used and presented in this paper.

REFERENCES

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

Durgunoglu, H.T. and Togrol, E. [1974], *State-of-the-Art Report on Penetration Testing in Turkey*, Proceedings ESOPT-1, Stockholm, June 1974, Vol 2.2, pp. 133-139.

Durgunoglu, H.T. and Togrol, E. [1995], *CPT in Turkey, National Report*, CPT'95 ISCPT, Linköping, Sweden, October 1995, Vol 1, pp. 243-252.

Emrem, C., [2000], *CPT as a Tool in Assessment of Soil Improvement Against Liquefaction*, Ph.D. Thesis, Boğaziçi 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.

Marchetti, S., P. Monaco, G. Totani, and M. Calabrese, [2001], *The Flat Dilatometer Test (DMT) in Soil Investigations,* A Report by the ISSMGE Committee TC16., Proc. IN SITU 2001, Intnl. Conf. on In-situ Measurement of Soil Properties, Bali, Indonesia, May 2001, pp 41.

Marchetti, S., P. Monaco, G. Totani and D. Marchetti, [2008], *In Situ Tests by Seismic Dilatometer (SDMT)* ASCE Geot. Special Publication GSP 170 honoring Dr. J. H. Schmertmann.

McGregor J.A. and J.M. Duncan, [1988], *Performance and Use of the Standard Penetration Test in Geotechnical Engineering Practice,* Virginia Polytechnic Institute and State University, pp. 80.

Olgun, C.G., Martin, J.R., Mitchell J.K. and Durgunoglu, H.T. [2001], *Improved Ground Performance During the 1999 Turkey Earthquake,* Proceedings of the 15th ICSMGE, August 26-29, 2001, Istanbul, pp 765-768

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.

Robertson, P.K. and R.G. Campanella, [1988], Guidelines for Geotechnical Design Using CPT and CPTU Data, *Civil Engineering Department University of British Columbia Vancouver,* B.C., Canada, pp. 74.

Youd T.L. and et al., [2001], *Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils,* Journal of Geotechnical and Environmental Engineering, ASCE, Vol.127, No.10, pp. 817-833

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