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CORRELATIONS OF DMT, CPT AND SPT IN NILE BASIN SEDIMENT

Hamza, M.[1] & Richards, D P[2]

1- Principal Associate, Hamza Associates, Cairo, Egypt
2- Senior Professional Associate, Parsons Brinckerhoff International, Cairo, Egypt

ABSTRACT:

The second line of the Cairo Metro-Phase 1- includes approximately 5.9 km of 9.40 m diameter tunnel, about 1.20 km of cut and cover tunnel constructed using diaphragm walls, seven new stations structures, and modification of two existing stations. The analysis and design of these underground facilities required an evaluation of the soil-structure interaction characteristics, particularly the in-situ modulus of deformation. In order to develop a reasonable estimate of this parameter, flat plate dilatometer tests were carried out at selected locations. The dilatometer (DMT) results have been correlated locally with CPT and SPT results to allow the prediction of the deformation values from conventional exploration methods without the necessity to carry out dilatometer tests at every site. These correlations are given and discussed in this paper.

1. INTRODUCTION

The second line of the Cairo Metro-Phase 1- includes 5.9 km of 9.40m diameter twin track soft ground tunnel which is executed by a pressurized face bentonite slurry shield. The Cairo Metro includes also about 300,000 m^2 of diaphragm walls for construction of cut and cover tunnel and stations. The tunnel crown depth varies from about 8.0 to 20.0 m below the ground surface with the static ground water level approximately 3.0 m below the ground surface. The diaphragm walls extend generally as deep as 50.0 m.

All underground structures are located entirely within the Nile River basin flood plain deposits of Quaternary age. These deposits vary in extent and character both laterally and vertically. Generally, the soil profile includes a surficial fill layer of sandy silt and clay underlain sequentially by a layer of silty clay to clayey silt of moderate plasticity, a layer of silty fine micaceous sand, and finally a deep deposit of medium to coarse sand which increases in density and coarseness with depth. The tunnels lie predominately within the latter deposit of sand, with the overlying layer of silty sand dipping down beneath the tunnel crown locally. The cut and cover excavations usually penetrate only the sediment sequences above the sand, even though the diaphragm walls extend much deeper.

Subsurface exploration for these structures included an extensive program of piezometers, borings, standard penetration tests (SPT), static cone penetration tests (CPT), and flat plate dilatometer tests (DMT). For structural design purposes it was required to determine the in-situ modulus of deformation. The modulus of deformation is an important input parameter in the numerical methods of analysis and design of most below grade structures, whether they are diaphragm walls, sheet pile cofferdam, or shield driven tunnels. All these structural types were an integral part of the Cairo Metro Line 2 Phase 1. Whether the parameter is used alone as "E" in an elastic/elasto-plastic analysis or as a parameter in determining the subgrade modulus value (k), it is still a necessary, but difficult parameter to define, especially when it is required to represent "in-situ" conditions. Various authors have described the application of these parameters for analysis and design of underground structures, including but not limited to, e.g. Clough and O'Rourke (1990) and Schmitt and Gilbert (1992) for diaphragm walls; and Muir-wood (1975), Rozsa and Kovacs (1979) and Duddeck (1985) for shield driven tunnels.

In this paper, the in-situ determination of the modulus of deformation was accomplished by the development of correlations between the more extensive cone penetration tests (CPT) and standard penetration tests (SPT) and the less frequent but more productive dilatometer tests (DMT). Correlations were first developed using empirical relationships reported in the literature for deformation modulus using the CPT and SPT data. These results were then compared to predictions using the DMT test results and a relationship was developed relating the DMT results to CPT results. These correlation between DMT, SPT and CPT represent similar concepts, but not necessarily the same results as those developed by Baldi, et. al. (1988, 1989).

2. PROJECT DESCRIPTION

2.1. Facilities

As noted previously, the study reported on herein were conducted as part of the detailed design of the Cairo Metro Line 2 Phase 1 which has been described in detail by Abdel Salam (1992). This line runs basically north-south through the center of Cairo on the east bank of the Nile River.

2.2. Site Geological and Geotechnical Conditions

The geology of Cairo is primarily related to Nile sediments, and in the vicinty of the Metro alignment, the near surface subsurface deposits are exclusively sediments of the Nile flood plain. The geological and geotechnical conditions for the Metro specifically have been described generally by Richards and Burchell (1994). Figure (1) shows a representative longitudinal geotechnical section for the soil deposits between Mubark and Attaba main stations. The profile of the tunnel is also indicated on the same figure. The geological formation along the route of the bored tunnel is a typical Cairo River Nile alluvial deposit. It is clear that there are four distinguishable main layers which are recognized as follows:

Layer 1 : Fill
It consists of pieces of asphalt, broken stones, broken red bricks in a matrix of sand silt and clay in variable percentages. The color is brown to dark brown and the layer has almost no cohesion.

Layer 2 : Clay
The soil is silty clay and occasionally clayey sand/silt. The clay includes calcareous particles of coarse silt size, contained as particles in the soil matrix, or accumulated as pockets a few centimeters in size. Also, small lumps of organic matter existed in some locations at random.

Layer 3 : Transition Zone
The prevailing soil classification of this layer is micaceous very silty fine sand with interbedded layers of clayey sandy silt. The deposit includes, at random, some gravel, broken pottery and medium size gravel of cemented sand. The prevailing colors of this layer are yellowish brown, yellowish grey and yellow. The layer is a transition between the silty clay above it, and the sand below it. This layer contains variable amounts of platty particles of mica and clay minerals. The range and limits of the grain size distribution curves for tested samples of this layer is given in Figure (2). In developing this figure, samples from the same layer recovered from several station areas were included to confirm the continuity of the layer.

Layer 4 : Sand
The sand is slightly gravelly to gravelly, slightly silty, varying from fine to medium sand to medium to coarse sand. Fine gravel was found at various depths and locations. Thin lenses of silty clays were also found through the sand layer. The range and limits of grain size distribution curve for tested samples of this layer are given in Figure (2). In developing this figure, samples from the same layer recovered from both tunnel and station areas were included to confirm the continuity of the layer.

Table 1 presents typical geotechnical parameters for the four main layers. It should be noted that the thickness of these layers as well as the geotechnical properties varied from one location to another along the tunnel route.

Location	Parameter							
	γ KN/m^3	K_o	Drained				Undrained	
			E' MPa	υ'	C' kPa	ϕ'	C_u kPa	E_u MPa
Layer 1	18	.58-.66	3-24	.35-.40	0	20-25	50	.34-25.0
Layer 2	18.5	.66	4-33.5	.40	0	20	75-100	4.5-38.5
Layer 3	19	.50	17.5-80	.35	0	30	—	—
Layer 4	20	.35-46	52-160	.30	0	33-41	—	—

Table. 1 : Summary, Geotechnical Parameters For Four Main Layers

3. SOIL EXPLORATION PROGRAM

A variety of techniques were used for subsurface exploration for Phase 1 of Line 2. These include the following techniques: 18 Vibro-percussion borings (VP), 10 Mazier sample borings (MZ) , 3 Standard penetration tests (SPT), 8 Static cone penetration test (CPT), 8 Dilatometer tests (DMT), and 16 Piezometers (PZ).

Of primary interest to this study, were the correlations developed between the DMT and the other more common test techniques, the SPT and CPT. Details of these correlations are discussed later, including a presentation of individual DMT test results.

4. THE DILATOMETER TEST

The soil deformability is measured using an in-situ dilatometer test, DMT. The Dilatometer Test, widely used in North America and Europe, is one of the more popular sounding methods available to the geotechnical profession because of its simple operation without the requirement for special electrical equipment, reproducible results, and use of a wide variety of penetration equipment and rods. In sand, the main useful application of DMT is to provide satisfactory estimates of deformability modulus.

The dilatometer used on this project is the standard hard steel blade which has a thin steel membrane on one side of the blade. After the blade has been inserted into the ground, the membrane expands by compressed gas. The pressures when the membrane lifts off the plane of the blade, and when the central expansion of the membrane reaches 1.1 mm are measured as P_o and P_1 respectively. Marchetti (1980) proposed the following indices:

Material Index $I_d = (P_1-P_o)/(P_o-U_o)$

Horizontal Stress Index $K_d = (P_o-U_o)/\sigma'_v$

Dilatometer modulus $E_d = 34.7\ (P_1-P_o)$

Where U_o is the in-situ equilibrium pore water pressure and σ'_v is the effective overburden pressure. The test mechanism is described by Marchetti (1980) and the test procedures are described in detail by Marchetti and Crapps (1981), and Schmertmann (1986).

Since the expansion occurs in a soil distorted by the penetration, and due to the horizontal direction of loading, E_d cannot be used directly, but must be multiplied by a correction factor. By correlating E_d to one-dimensional vertical tangent modulus M, Marchetti (1980) found $M = R_m . E_d$, where R_m is a factor given as a function of K_d. Since E_d was correlated directly to M, the factor R_m already incorporates the modulus anisotropy factor. Note that the factors I_d and K_d reflect to some extent, the soil type and stress history, which are also important in determining the anisotropy ratio. Young's modulus É can be obtained from constrained modulus M using the equations of elasticity with an approximate value of Poisson's Ratio equals 0.3, leading to É = 0.75 M.

As pointed out above, DMT was chosen primarily to obtain reasonable estimate of deformability modulus. DMT modulus are presumably more accurate than any values inferred from penetration resistance for at least the following two reasons (Schmertmann,1986):

. DMT blade causes less soil distortion than conical tips,

. DMT actually measures a modulus, while cone resistance measures only bearing capacity.

The good agreement between settlements predicted using M obtained from DMT and measured settlements is documented by a large number of case-histories e.g. Schmertmann (1986), Hayes (1990), Lacasse and Lunne (1986), and Iwasaki et al. (1991).

5. RESULTS OF FIELD TESTS

At eight locations selected by the tunnel designers, CPT and DMT were carried out at 2 meters distance apart to provide a profile of CPT and DMT for possible correlations. The work was carried out using a CPT machine for both tests. Table (2) indicates the ground elevation and depth of penetration of CPT and DMT tests, and Figure (3) shows a representative profile of Dilatometer test results with depth at one location as an example for the interpretation of test results. For brevity, detailed plots of CPT results are not included herein.

Sounding No.	Sounding Elevation	Sounding Depth (m)	K.P. (kilometer Point)
CPT./DMT. 1	18.75	13.40/13.00	3.545
CPT./DMT. 2	18.50	24.60/13.20	5.563
CPT./DMT. 3	19.00	29.00/28.80	6.550
CPT./DMT. 4	21.80	13.00/12.80	7.145
CPT./DMT. 6	19.12	12.80/19.00	8.095
CPT./DMT. 7	21.25	14.80/13.40	8.779
CPT./DMT. 8	21.33	17.00/13.40	9.020
CPT./DMT. 9	21.11	24.80/18.40	9.762

Table. 2 : DMT/CPT Summary

CPT and DMT results were then used to obtain a correlation between the q_c value of the CPT and $M = 1/m_v$ value of the DMT. Profiles of q_c and $M = 1/m_v$ were plotted to the same depth scale as shown in Figures (4) to (7). The two values provided the same pattern with depth, indicating an excellent correlation for this long site. In order to quantify the correlation, the relation between q_c and M was plotted for the four layers.

For the fill layer (layer 1) the q_c versus M plot is presented in Figure (8). The best linear fit provided the following equations:
$M_{DMT} = 8\ q_c$, and $\acute{E} = 6\ q_c$

For the clay layer (layer 2), the q_c versus M plot is presented in Figure (9) and the best linear fit resulted in the following equations:
$M_{DMT} = 7.5\ q_c$, and $\acute{E} = 5.63\ q_c$

For the micaceous silty sand layer (layer 3), the q_c versus M plot is presented in Figure (10) and the suggested power type relationship provided the following equations :
$M_{DMT} = 8.7\ q_c^{1.3}$, and $\acute{E} = 6.53\ q_c^{1.3}$

For the sand layer (layer 4), the q_c versus M plot is presented in Figure (11) and the suggested power type relationship provided the following equations :
$M_{DMT} = 1.23\ q_c^{1.53}$, and $\acute{E} = q_c^{1.53}$

The family of equations representing the relationships between M_{DMT} and q_c are given in Figure (12) for all layers. The above relationships enable the evaluation of soil deformability from CPT and q_c values. This procedure should provide better deformation modulus É from CPT, than those evaluated directly from q_c employing conventional published correlations. However, the conventional published correlations shall be used hereinafter for comparisons.

Approximate deformation moduli; É, for layer 3 were evaluated from CPT and SPT using empirical formula based on correlations relating q_c of CPT and N of SPT to É. The four SPT carried out in the same sand, layer 3, at the stations are used. The three empirical formula applied to SPT N values to provide a range of values of É are:

1. Denver (1982) gave the following parabolic correlation between N and É
$E = B\ N^{0.5}$ where B = 7 Mpa
2. Bowles (1982) proposed the following correlation between the N and É
$E = 50\ (N + 15)\ t/m^2$
3. Webb (1970) proposed that the relation between N and É can be approximated by the following relation
$E = 478\ N + 7170$ kPa

A typical correlation with depth for Young's modulus as estimated from SPT values is shown in Figure (13).

The three empirical formula applied to CPT q_c to provide a range of values of É are :
1.$\acute{E} = 2 * q_c$(After Schmertmann, 1986)
2.$\acute{E} = 2.5 * q_c$(After Mitchell and Gardener,1975)
3.$\acute{E} = 8\sqrt{q_c}$(After Denver, 1982)

A typical correlation with depth for Young's modulus as estimated from CPT value is shown in Figure (14), and a typical Young's modulus correlation profile with depth between CPT and DMT is shown in Figure (15).

By Comparing the Young's Modulus estimates in Figures 13,14, and 15, it can be seen that the modulus values show the same increasing trend with depth as with the CPT and PMT estimates. It can be seen also, that the modulus values for either CPT or SPT correlations agree quite well for the different correlation equations used.

6. CONCLUSIONS

Recognizing that the in-situ deformation characteristics of soils are difficult to define, but are necessary parameters for the analysis and design of underground structures, correlations have been developed by standard subsurface exploration techniques such as SPT and CPT. These correlations can be used to estimate the deformability parameters for the near surface (<50 meters) unconsolidated sediments of the Nile River flood plain deposits. Relationships have been presented to correlate CPT and SPT test data to deformability parameters based upon DMT test data at the same locations and depths. Although the correlations represent a relatively small data base over a small geographic area, it is believed by the authors that the presented correlations represent an improvement in the knowledge of the subsurface soil parameters in

Cairo, and those correlations could be expanded to provide a wider data base not only for Cairo, but also to other geographic locations where the in-situ deformation characteristics of the subsoils are required.

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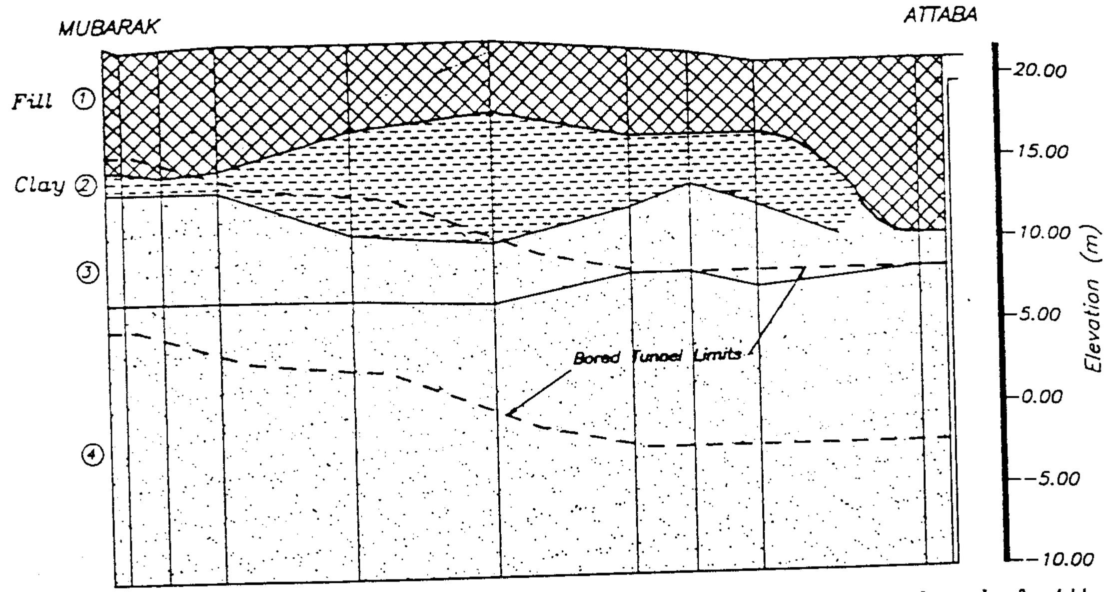


Fig.(1) Geotechnical Longitudinal Section for Lot (20) Between Moubarak & Attaba

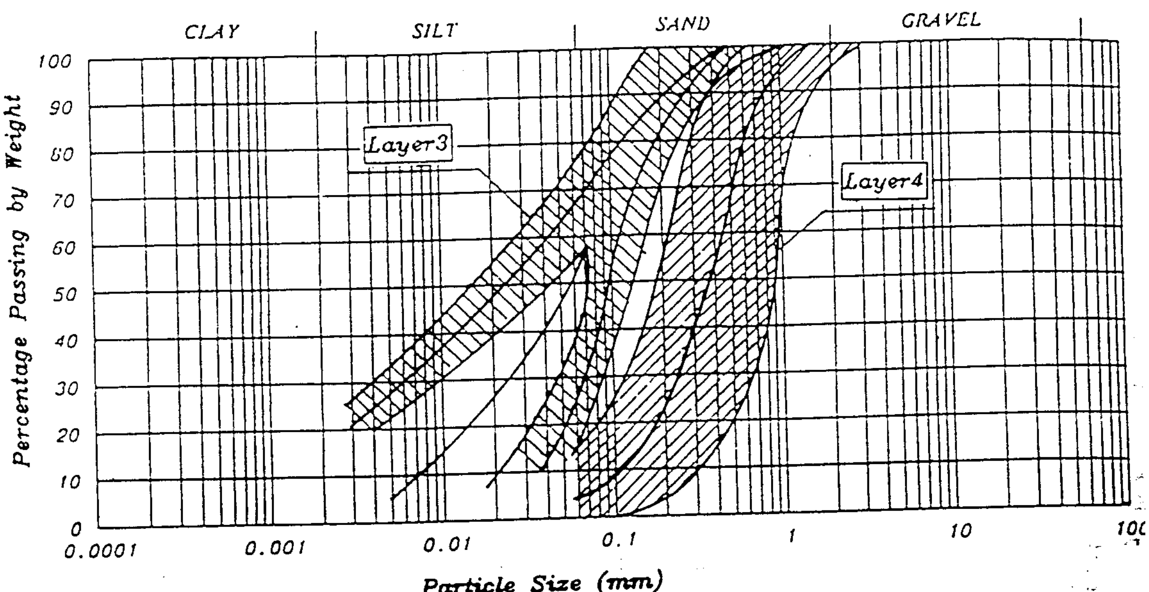


Fig.(2) Range of Grain Size Distribution For Layer (3 & 4)

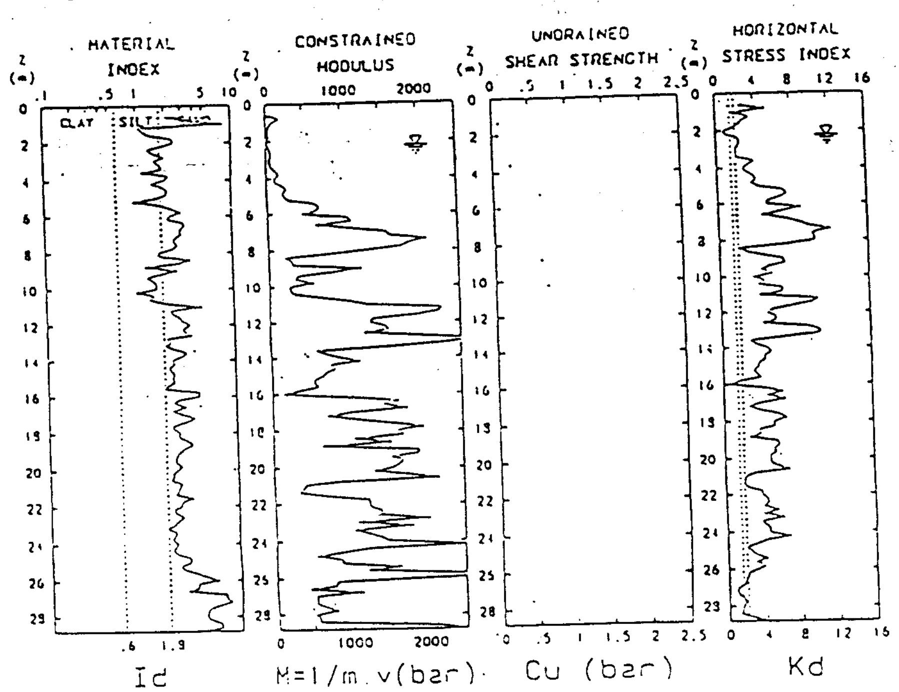
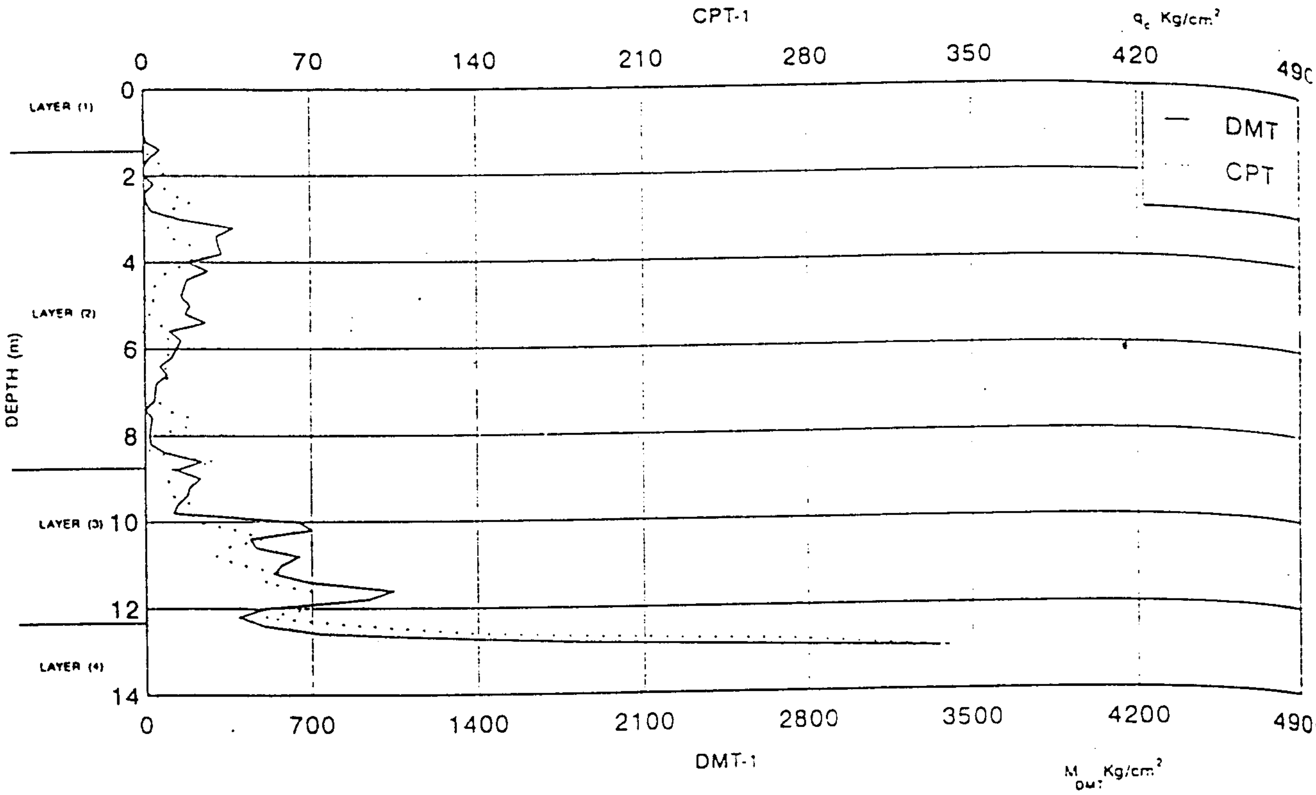
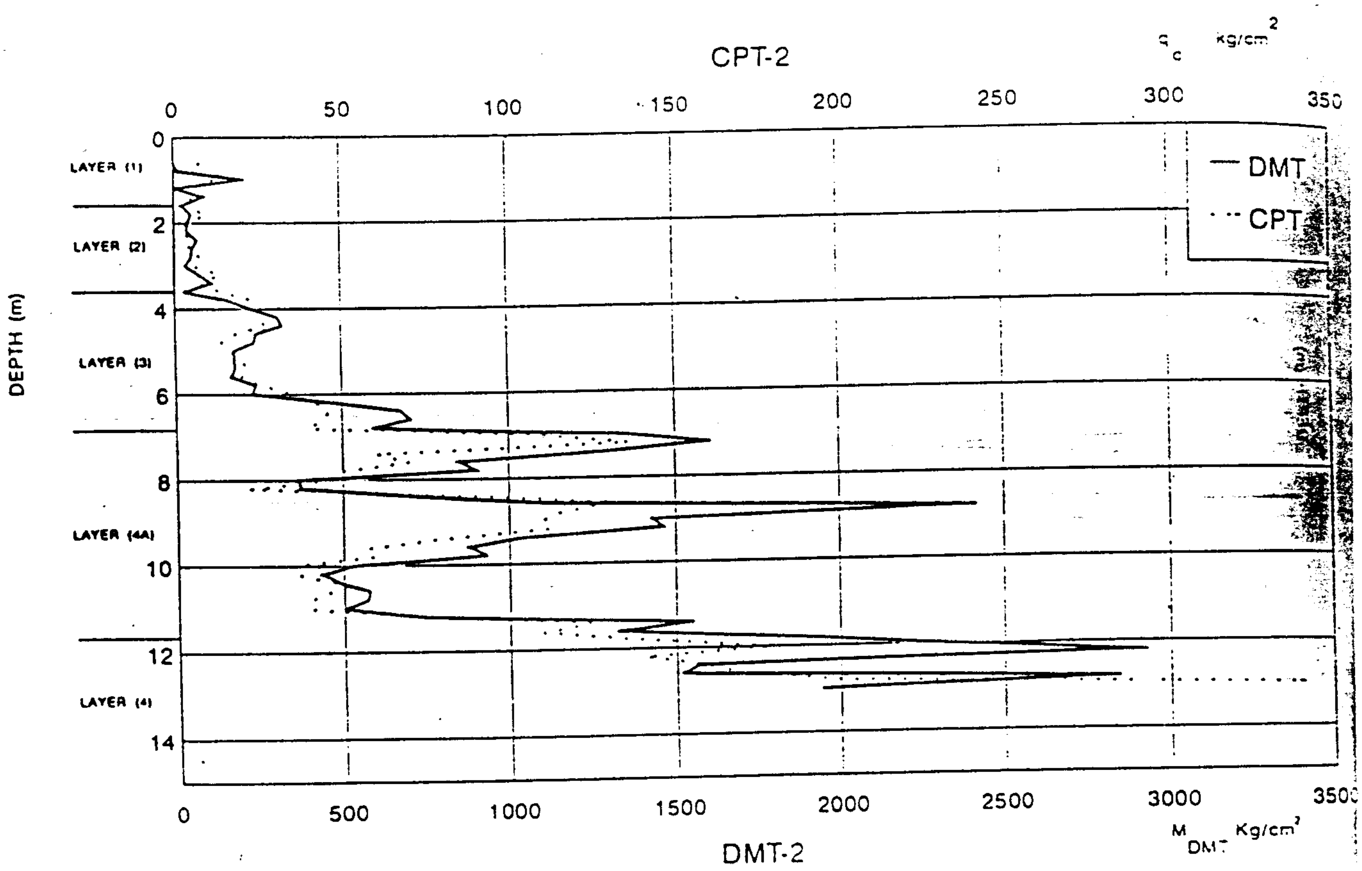


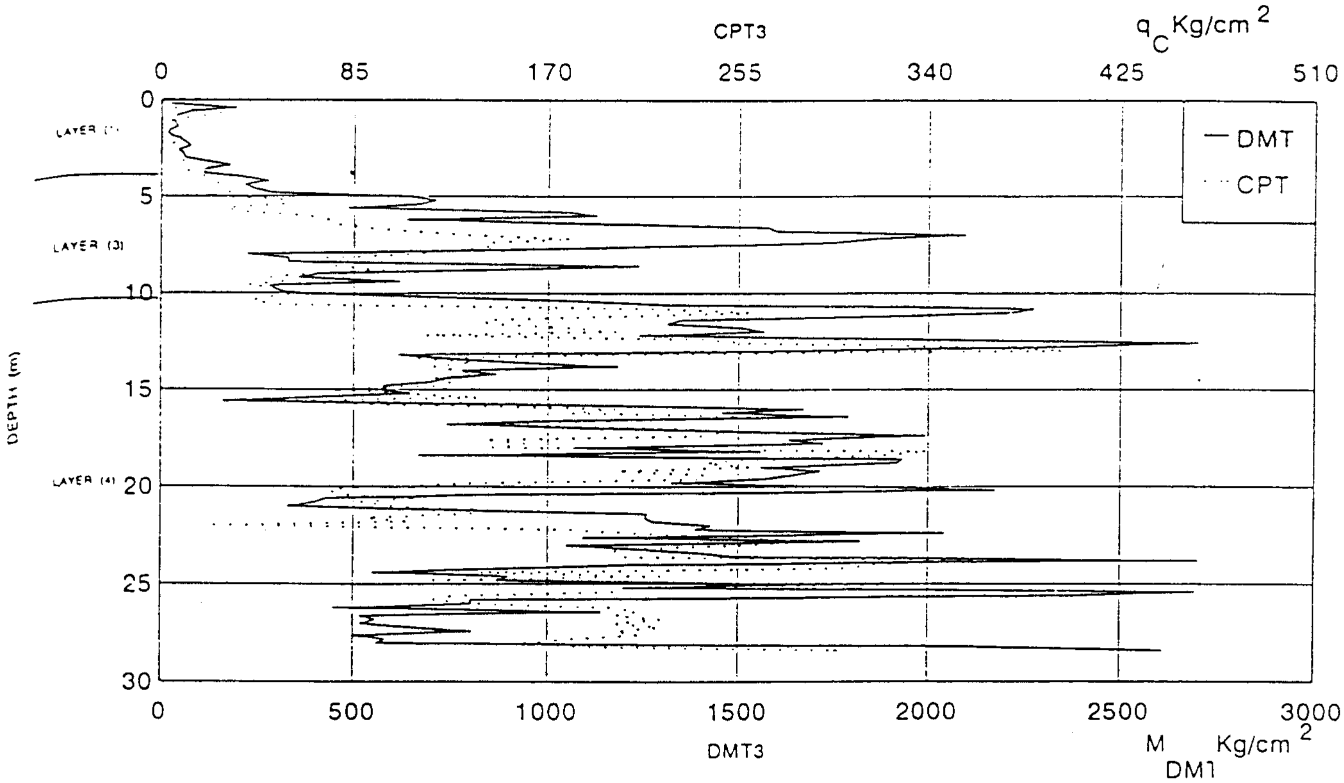
Fig.(3) Typical Dilatometer Test Record



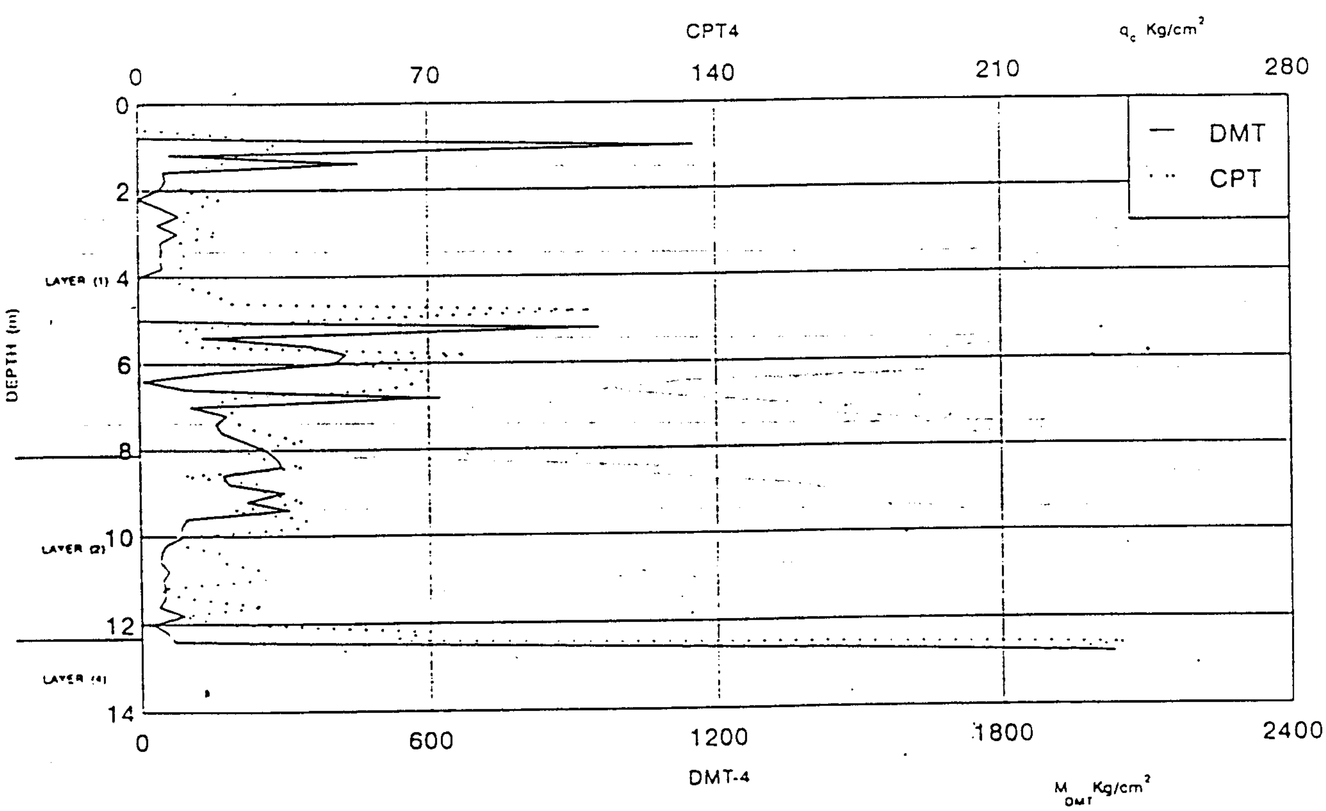
Fig(4) Profile of DMT1 & CPT1 with depth



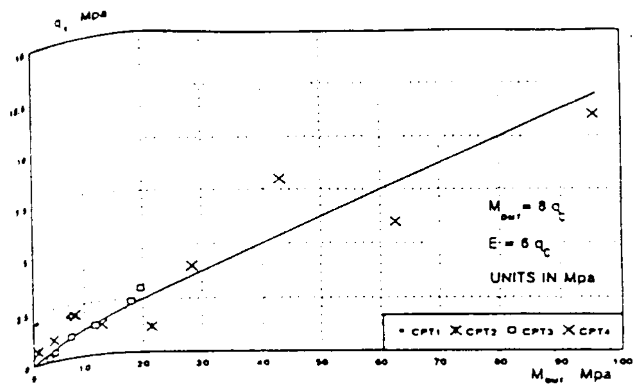
Fig(5) Profile of DMT2 & CPT2 with depth



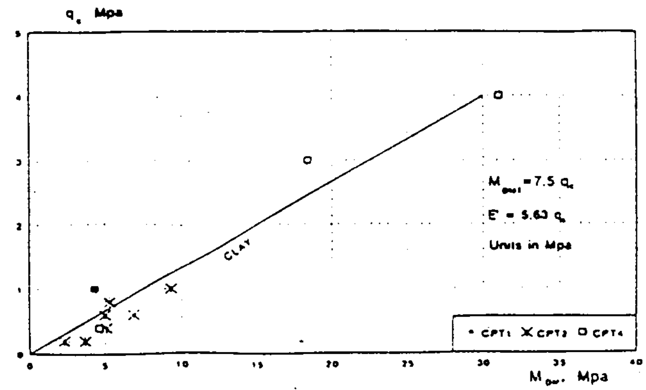
Fig(6) Profile of DMT3 & CPT3 with depth



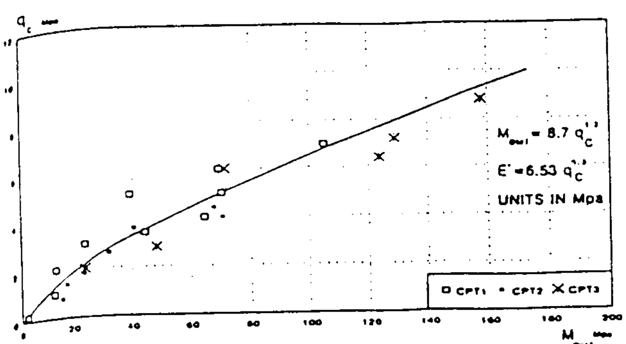
Fig(7) Profile of DMT4 & CPT4 with depth



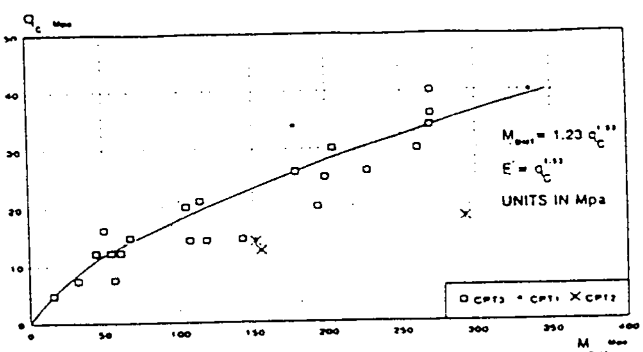
Fig(8) Correlation between M from DMT & q_c of CPT for layer(1)



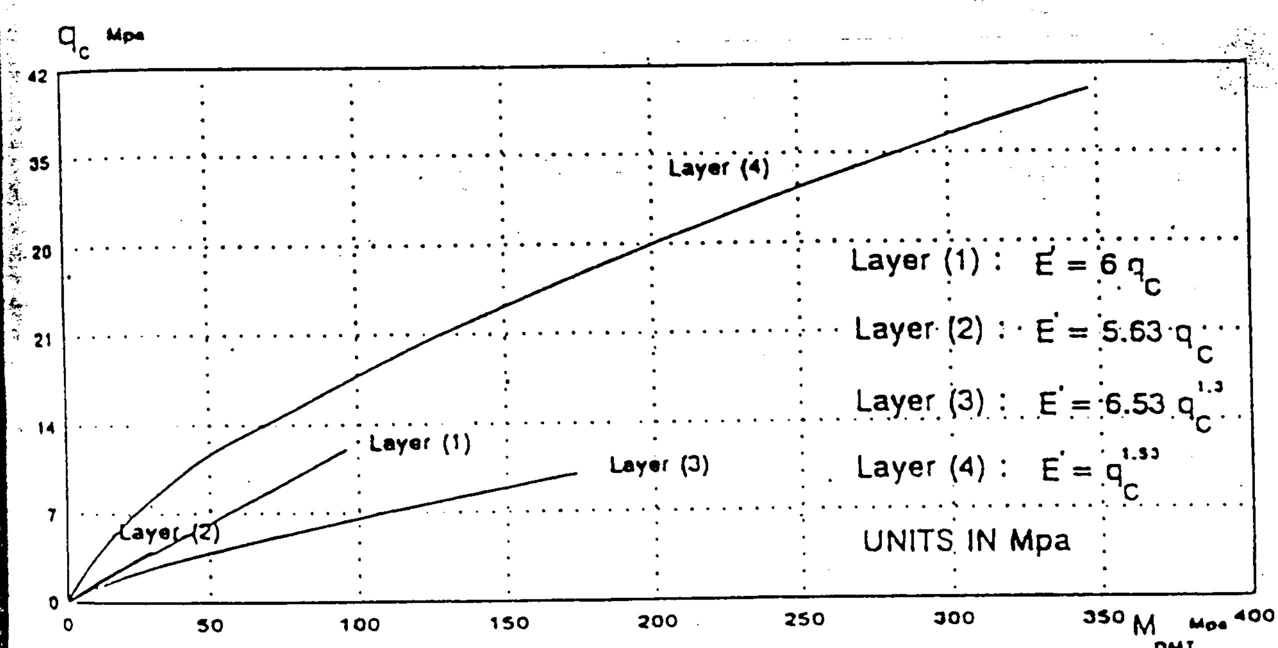
Fig(9) Correlation between M from DMT & q_c of CPT for layer(2)



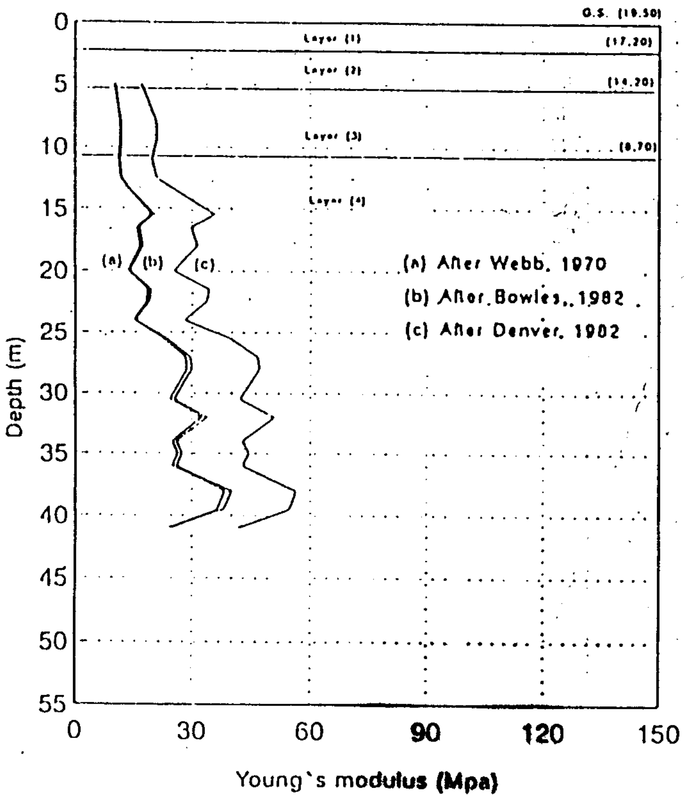
Fig(10) Correlation between M from DMT & q_c of CPT for layer(3)



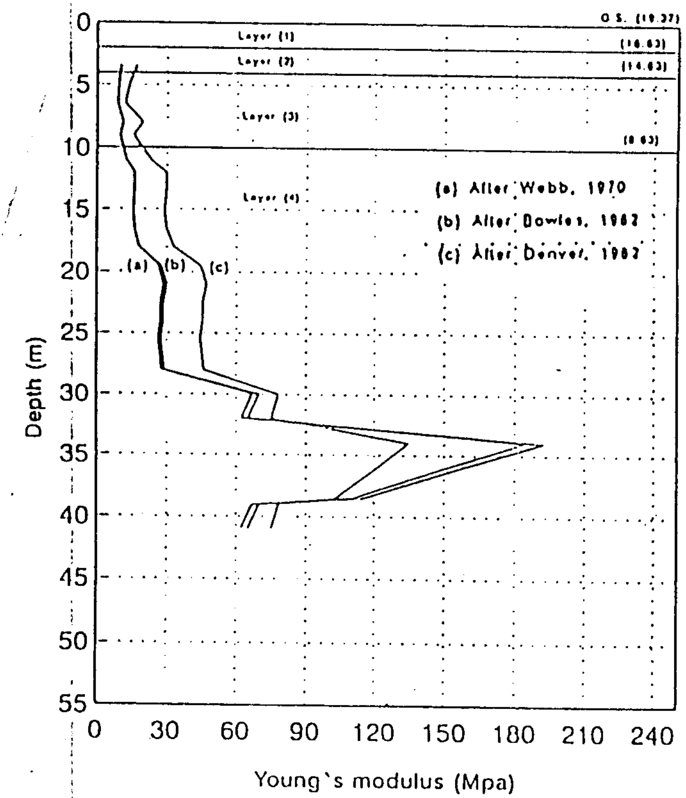
Fig(11) Correlation between M from DMT & q_c of CPT for layer(4)



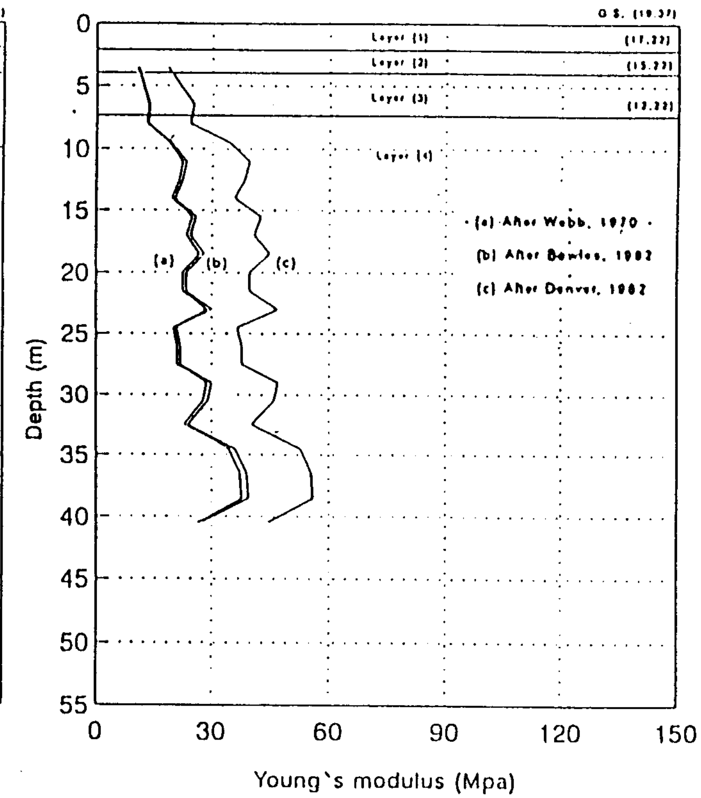
Fig(12) Family of curves presenting the relation between ... using correlations with DMT



Fig(13) Estimated Young's modulus profile from BH(47) SPT



Fig(14) Estimated Young's modulus profile from CPT32



Fig(15) Estimated Young's modulus profile from CPT 40 results and correlations from Dilatometer