*Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering*

*doi:10.3233/978-1-61499-656-9-651*

# The Newcastle Dilatometer testing in Lahore cohesive soils

## Le New Castle Dilatometer testant dans Lahore cohesive sols

A. Akbar
*Civil Engineering Department, University of Engineering and Technology, Lahore, Pakistan*
S. Kibria
*Geotechnical & Geo-environmental Engineering Division, NESPAK, Lahore, Pakistan*
B.G. Clarke
*Civil Engineering Department, University of Newcastle Upon Tyne, UK*

ABSTRACT

The Newcastle Flat Rigid Dilatometer (*NDMT*) is a new in-situ soil testing device developed in 2001 for direct measurement of the in-situ characteristics of soils such as strength, stiffness, deformation etc. It is quite simple, robust and produces repeatable data with no hysteresis. The *NDMT* loads the soil with a relatively rigid piston of 3 mm thickness in lieu of only 0.2 mm thick membrane of Marchetti Dilatometer (*MDMT*), thus creating a loading environment closer to that of the real-life foundations. The *NDMT* is more sensitive than the Marchetti dilatometer in measuring pressure and the corresponding displacement because of the instrumented rigid plate and therefore has the potential to detect variations in soil strength or stiffness with depth more accurately.

This research paper is based on the *NDMT* testing at three locations in the cohesive soils of Lahore (near Thokar Niaz Beg) up to 8.0 m depth below the natural surface level. In order to correlate the *NDMT* test results with those of other conventional methods, *SPT*s were carried out and undisturbed soil samples (*UDS*) were recovered in thin walled Shelby tubes at locations close to the *NDMT* testing locations. The undisturbed soil samples were tested for grain size analysis, Atterberg limits and unconfined compression strength in the laboratory.

The *NDMT* indices viz. material index ($I_D$), dilatometer modulus ($E_D$), and horizontal stress index ($K_D$) have been evaluated from the corrected load – deformation curves of each *NDMT* test. Subsequently, new correlations have been developed between dilatometer indices and conventional soil characteristics such as classification, undrained shear strength and elastic modulus, for the Lahore clayey silts/silty clays.

RÉSUMÉ

Le New Castle Flat Rigid Dilatometer (*NDMT*) est un nouveau dispositif pour tester le sol in situ, développé en 2001 pour le mesure direct des caracteristiques des sols in situ comme, la solidité, la déformation. Cést très simple, robuste et prodiut les données répétable. Le *NDMT* charge le sol avec un piston d´ éppaisseur 3mm au lien de seulement 0.2mm épaise membrane de Marchetti Dilatometer (*MDMT*) donc créant un enviornnement plus proche des fondations réelles. Le *NDMT* est plus délicat que le dilalometer Marchetti pour mesurer la pression et le déplacement correspondant, à cause de la planche rigide et donc a le potentiel à détecter les variations dans la solidité de sol avec une précision.

Cette recherche est basée sur le *NDMT*, testant dans les sols cohésifs de Lahore à trois locutions (prés de Thokar Niaz Beg) jusqu'au 8.0m de profondeur au dessous de niveau de la surface naturelle. Pour mettre en correlation les resultats de testes du *NDMT* avec ceux d'áutres méthodes conventionelles, SPTs étaient mis à execution et les échantillons des sols (*UDS*) étaient recouvert dans les tubes shelby aux locutions, près ceux de *NDMT*. Les échantillons des sols étaient testés pour analyser la taille du grain. Les limites d' Atterberg et la compression non-confiné au laboratoire.

Les indices *NDMT* vis à vis l' index materiel ($I_D$) dilalometer modulus ($E_D$), et l' index de stress horizontale ($K_D$) ont été evalué du charge corrigé - les courbes de déformation de chaque teste *NDMT*. Par la suite, les nouvelles correlations ont été développées entre les indices dilalometer et les caracteristiques de sol conventionnel comme la classification, la solidité et les modulus élastiques pour les argiles de limon.

## 1 INTRODUCTION

The evaluation of strength and deformation characteristics of soil deposits has always been an area of key interest for design engineers. For this purpose, a host of techniques have been developed, over years, for representative sampling, laboratory testing and in-situ testing. Whereas, depending upon the type of the soil deposit, laboratory tests on the disturbed/undisturbed soil samples may not necessarily provide a reliable estimate of the in-situ properties; the in-situ testing offers a better and a reliable option in this regard.

Ever since the appearance of the first use of penetration tests, the engineers and the scientists have continuously endeavoured to assess the in-situ strength, stiffness and stress. This has led to an improvement in the analyses required for the design of foundations and cut slopes, which has resulted in considerable saving of time and money.

Like various other engineering techniques used in the evaluation of geotechnical design parameters, the in-situ testing is also beset with the problem of some disturbance of the soil during insertion of the test device in the ground as well as with the difficulty of interpretation of test results. This difficulty in the interpretation of the test results is primarily owing to the complex behaviour of soils, together with the lack of control and of choice of the boundary conditions in any field test.

The first patent of a dilatometer viz. the Marchetti dilatometer (*MDMT*) is a simple device that can be used to determine in-situ stress, stiffness and strength of a soil with some degree of confidence. However, the *MDMT* is not robust enough to test soils like glacial till, as the membrane can tear. It is for this reason that a new blade has been developed that can be used in a greater variety of soils. The new dilatometer viz. the *NDMT* has a significant promise of serving as an alternative soil characterization method. It affords in-situ measurement of various soil properties like classification, shear strength, stiffness, in-situ stress state etc. Akbar (2001) presents the design of the *NDMT* together with in-situ testing procedures, data analysis techniques and comparison of the results with those from the *MDMT*.

This research is based on testing the alluvium of southern Lahore with the *NDMT* at a site near Thokar Niaz Beg. Thereafter, correlations of *NDMT* indices with the traditional soil properties/geotechnical design parameters have been established.

## 2 THE NEWCASTLE FLAT DILATOMETER (*NDMT*)

Figure 1 shows the *NDMT* blade (i) whose geometry is the same as that of the Marchetti Dilatometer. The membrane of the *MDMT* is replaced with the piston assembly (ii) shown in Figure 1. The use of a wave spring washer under the piston keeps the piston flush with the blade until the piston is pressurized using dry Nitrogen gas and brings the piston back when depressurized. Two O-rings are incorporated in the *NDMT* to keep the assembly air and water-tight. The applied gas pressure is recorded using a pressure transducer.

A system of Hall Effect Transducer (*HET*) and a magnet is used for measuring the displacement of the piston. The magnet is fixed at the center of moving piston while the *HET* is fixed to the body of the blade in front of the magnet. When the piston moves by internally pressurising the blade, the *HET* produces a change in its output according to the flux intensity. This output is non-linear but non-hysteretic and a second-degree curve fits the data (Akbar 2001). Access to the connections between the *HET* and the cable is via steel cover plate (iii in Figure 1). The output of the pressure transducer and the *HET* are read and recorded by a computer. The blade can be jacked/pushed to the test level in various strata.

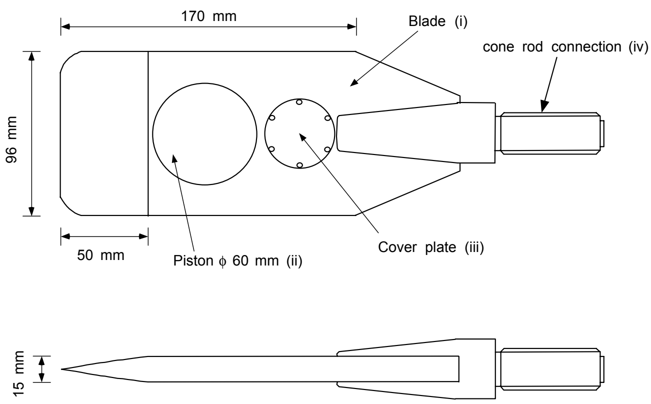


Figure 1 The Newcastle flat rigid dilatometer (*NDMT*)

## 3 SITE OPERATIONS

The *NDMT* equipment was assembled on-site. After performing the system compliance calibration, the probe was pushed into the ground using a skid mounted straight rotary drilling rig. Tests were conducted immediately after the blade reached a test depth to perform tests under undrained conditions. Where advancing of the *NDMT* probe by the rig was not possible due to hard stratum, the *NDMT* was withdrawn. Thereafter, the test level was achieved by augering and the *NDMT* probe was again lowered in the borehole.

The tests were carried out at various levels, generally 20 to 50 cm apart, so as to meet the research objectives. These depths corresponded to the levels of *SPT* performed and *UDS* recovered from the adjacent boreholes.

During the testing, the pressure was applied through a pressure regulator having needle valve system; the same as in the *MDMT*. After attaining 1.1 mm penetration of the piston, the pressure was vented off. Each test took between 1 and 3 minutes. No unload-reload cycles during tests were included in this study. At the end of testing at each location, the instrument was withdrawn and calibrated for system compliance. The calibrations before and after the in-situ testing were averaged. The in-situ pressure~deformation curves were then corrected for system compliance.

## 4 INTERPRETATION OF TEST DATA

Figure 2 shows a typical test curve. The corrected load-deformation curves of each *NDMT* test have been analyzed to find the representative pressures ($p_B$, $p_E$ and $p_{1.1}$) and the appropriate indices ($I_D$, $K_D$ and $E_D$), as discussed in the following Sections

As shown in Figure 2, $p_B$ represents that pressure on the load-displacement curve where the piston just starts moving and the soil in front of the piston is under elastic yielding. This can also be termed as the take-off pressure.

The precise evaluation of pressure $p_E$ (as defined in Figure 2) is of paramount importance, as it directly affects the material index ($I_D$) and the horizontal stress index ($K_D$). Four different methods have been attempted to evaluate the $p_E$ pressure as follows:

(a) Pressure at intersection of elastic and plastic regions
(b) Tangent to the yield curve to intersect the pressure axis
(c) Tangent to log pressure – displacement curve
(d) Tangent to log pressure – log displacement curve

A comparison of the $p_E$ pressures from these Methods shows that the $p_E$ pressures calculated by methods (b) and (c) are consistent and fairly close to each other; the method (c) based $p_E$ pressures being higher than the Method (b) based $p_E$ by upto about 7% (Kibria, 2004). Finally method (c) has been used in the interpretation of the data owing to better distribution of data points.

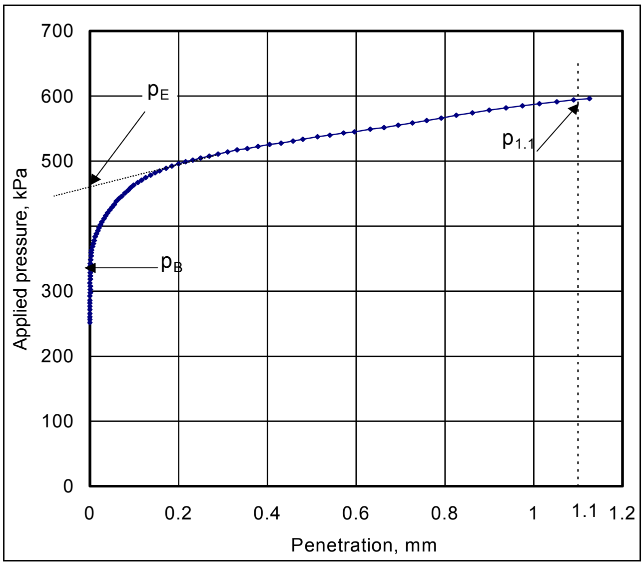


Figure 2 A typical *NDMT* test curve for constant rate of stress loading (*CRS*)

The pressure required to cause 1.1 mm displacement of the rigid piston of the *NDMT* was picked from the corrected curves.

The three pressures ($p_B$, $p_E$ and $p_{1.1}$) together with the effective overburden pressure at the test depth were converted to a dilatometer modulus ($E_D$), a horizontal stress index ($K_D$), and a material index ($I_D$), using the following equations:

$$K_D = \frac{p_E}{\sigma'_v} \quad (1)$$

$$I_D = \frac{p_{1.1} - p_E}{p_E} \quad (2)$$

$$E_D = 42.8(p_{1.1} - p_B) \quad (3)$$

The $I_D$ and $E_D$ values obtained in this research, result into plotting of the data points in the zones of coarser soils than those actually met at the site, on the Marchetti and Crapps (1981) Soil Description Chart (originally developed on the basis of *MDMT* testing). This finding calls for devising a separate system of classification of soils for the *NDMT* data. The analysis has resulted into adopting the following arbitrary multiplier coefficients to adjust both $I_D$ and $E_D$ coefficients for the classification purpose (Kibria, 2004) for the three soil groups met at the site.

| *NDMT* property | Multiplier coefficient for | | |
|---|---|---|---|
| | Non-Plastic ML soils | Plastic ML soils | CL soils |
| $I_D$ | 0.55 | 0.25 | 0.20 |
| $E_D$ | 0.90 | 0.90 | 0.85 |

These coefficients are considered good for classification of relatively fine grained soils (silts & clays) on the basis of *NDMT* testing. More testing will be required to validate/finalize these multiplier coefficients.

## 5 UNDRAINED SHEAR STRENGTH, $s_u$

The undrained shear strength obtained from the unconfined compression tests has been compared with those estimated using three methods viz. Loading Slope method (Akbar, 2001), Marchetti formula (1980) and Roque et al. method (1988).

In order to obtain the undrained shear strength by Akbar method, the $\log_e$ of cavity strain (defined as the piston displacement divided by half the blade thickness) was plotted against the applied pressure. The slope of the 1st degree trend line over 3 to 5% cavity strain gives the $s_u$ value.

The Marchetti formula (1980) for soft clays (though strictly valid for $I_D \le 1.2$) has been used as under:

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

Finally, $s_u$ was also estimated using Roque formula, as under:

$$s_u = (p_{1.1} - \sigma'_{ho}) / N_c \quad (5)$$

where $\sigma'_{ho} = K_o\ \sigma'_{vo} + u_o$

$\sigma'_{ho}$ was estimated at the middle of the pressure bulb and $N_c$ was taken as 9 ($N_c$ varies from 5 to 9; the lower value being for brittle soils).

A comparison of the undrained shear strength obtained from the unconfined compression test with that obtained from the *NDMT* test by the above-explained three methods delineates that:

- Akbar's Loading Slope method and Roque method overestimate the $s_u$ by about 100% on the average, in comparison with the laboratory values.
- Marchetti's method underestimates the $s_u$ by about 50%, in comparison with the laboratory values.

Akbar (2001), however, considers the Loading Slope method to be the most reliable method for obtaining $s_u$ in cohesive soils. He has based this conclusion on the basis of the study in the U.K. While favouring the Loading Slope method, Akbar (2001) has pointed out major discrepancies of the laboratory based $s_u$, which include disturbance of samples during extraction, transportation, extrusion and specimen preparation stages. The effect of these factors is inevitably manifested by the large scatter in the laboratory measured $s_u$ values.

A comparison of Akbar's Loading Slope method based $s_u$ with those from other methods concludes that:

- Roque method based $s_u$ values are fairly close to Akbar method based $s_u$. The Roque values are underestimated by upto 10%.
- Marchetti method underestimates $s_u$ by about 67% on the average compared to the Akbar values.
- The laboratory (unconfined compression test) based $s_u$ show an erratic scatter of data.

Therefore, modified Roque formula is presented as under, for using the *NDMT*:

$$s_u = \frac{1.1 \text{ x } (p_{1.1} - \sigma'_{ho})}{N_c} \quad (6)$$

Similarly, the modified Marchetti formula for using the *NDMT* data is as under:

$$s_u / \sigma'_{vo} = 0.66\ (0.5\ K_D)^{1.25} \quad (7)$$

The plot of $s_u/\sigma'_{vo}$ vs. $K_D$ using Akbar's Loading Slope (2001) approach for the determination of $s_u$, leads to the development of the following correlation:

$$s_u / \sigma'_{vo} = 2.4\ (K_D)^{1.16} \quad (8)$$

More *NDMT* test data will be required to validate the relationships, proposed as above.

## 6 SPT, N VERSUS DILATOMETER MODULUS, $E_D$

The field SPT blows ($N_{field}$) were plotted against the dilatometer modulus ($E_D$) for all the data. The plot shows a wide scatter of data. However, the average trend line has the following equation:

$$E_D\ (\text{MPa}) = 2.9\ N_{field} + 5.5 \quad (9)$$

## 7 QUICK ESTIMATION OF SOIL PROPERTIES

Logically, the pressure $p_{1.1}$ is inversely proportional to the natural moisture content ($m$) and directly proportional to dry density ($\gamma_d$) and undrained shear strength ($s_u$) of a soil. Based on the present study, the following correlations have been developed (Kibria, 2004):

$$\text{Coefficient } C_1 = \gamma_d \times s_u / m^2 \quad (10)$$

$$\text{and} \qquad \text{coefficient } C_2 = \gamma_d^{\,2} / m \quad (11)$$

Where,

$C_1 = 2E - 10p_{1.1}^3 - 5.36\ E - 7p_{1.1}^2 + 0.0005p_{1.1} + 0.0665$ and

$C_2 = 1E - 10p_{1.1}^3 - 3.33E - 7p_{1.1}^2 + 0.0004p_{1.1} - 0.0499$

The above equations provide simple means to evaluate $p_{1.1}$ for cohesive soils on the basis of their $m$, $\gamma_d$ and $s_u$. In addition, the pressure ratio $p_{1.1}/p_E$ for the cohesive soils when plotted against $p_{1.1}$ generated a straight line trend given by the equation:

$$p_{1.1}/p_E = 0.0016p_{1.1} + 1.4571 \quad (12)$$

Thus with the pressure $p_{1.1}$ already known, the pressure $p_E$ can also be evaluated for the cohesive soils. Therefore, $K_D$ and $I_D$ and thereafter many soil characteristics can be easily estimated on the basis of only $m$, $\gamma_d$ and $s_u$. Conversely, with the knowledge of $p_{1.1}$ and $p_E$, estimates of $m$, $\gamma_d$ and $s_u$ can also be made.

## 8 CONCLUSIONS

A number of correlations have been developed between *NDMT* indices and soil properties. Multiplier coefficients to $I_D$ and $E_D$ evaluated on the basis of the *NDMT* testing have been recommended for classification of cohesive soils according to the Marchetti and Crapps (1981) Soil Description and Unit Weight Chart.

Other correlations developed include those for evaluation of undrained shear strength, and elastic modulus. The *SPT* blows have also been correlated with the dilatometer modulus.

Besides, an empirical procedure has also been evolved to estimate the *NDMT* indices and thereafter various soil characteristics on the basis of natural moisture content, dry density and/or undrained strength of cohesive soils. Conversely, with the knowledge of $p_{1.1}$ and $p_E$, estimates of $m$, $\gamma_d$ and $s_u$ can also be made. However, this instrument is new and has undergone limited testing so far. More in-situ testing is required before making rigorous comments. However, the present research indicates that the *NDMT* has a promise to replace/reduce the quantum of conventional drilling, sampling and laboratory testing, thus saving a lot of time and money on engineering projects. It is anticipated that further research on *NDMT* will help accumulate an adequate database to develop a quick, cheap and reliable alternative soil investigation technique for evaluation of not only the conventional soil properties but also sensitive in-situ characteristics such as coefficient of earth pressure at rest ($K_o$) and overconsolidation ratio (*OCR)*.

## REFERENCES


Akbar, A. (2001), "Development of Low Cost In-situ Testing Devices," *Ph.D. Thesis*, Civil Engineering Department, University of Newcastle, UK.

Akbar, A. and Clarke, B.G. (2001), "A Flat Dilatometer to Operate in Glacial Tills," *Geotechnical Testing Journal*, GTJODJ, Vol. 24, No.1, pp. 51-60.

Akbar, A. and Clarke, B.G. (2002), "A New Robust Device for the Identification of Potential Slip Surfaces" 3rd *Int. Conf. on Land Slides, Slope Stability and the Safety of Infra Structures*, July 11-12, 2002, Singapore.

Kibria, S. (2004), "Evaluation of In-situ Characteristics of Southern Lahore Alluvium Using Newcastle Dilatometer", *M.Sc. Thesis*, Civil Engineering Department, University of Engineering and Technology, Lahore-Pakistan.

Marchetti, S. (1980), "In Situ Tests by Flat Dilatometer," *J. Geotech Engng Div*., *ASCE*, Vol. 106, No. GT 3, pp 299-321.

Marchetti, S. and Crapps, D.K. (1981), "Flat Dilatometer Manual," *GPE Inc., USA*.

Marchetti, S. (1997), "The Flat Dilatometer Design Applications," *Proceedings, Third Geotechnical Engng. Conference, Cairo University, Egypt*, pp. 1-25.

Roque, R., Janbu, N., and Senneset, K. (1988), "Basic Interpretation Procedure of Flat Dilatometer Tests," *Proceedings of the 1st Int. Symposium on Penetration Testing, ISOPT-1, Orlando, Florida*, Vol.1, pp 577-587