34. The interpretation of the Marchetti dilatometer test in UK clays

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The Marchetti dilatometer (DMT) has been used on a wide variety of UK soils ranging from soft normally consolidated to stiff heavily overconsolidated clays on well documented sites where reference soil properties are known. The device has proved to be robust and simple to use and gives very repeatable results. However it has been found that the DMT assessed properties are generally in error and new correlations are suggested in an attempt to make the DMT more applicable to these UK soils; possible reasons for the discrepancies have also been suggested.

INTRODUCTION.

1. The Marchetti dilatometer (DMT) (ref. 1) is a simple, robust insitu testing device with the potential, in clays, to give soil properties such as density, undrained shear strength, overconsolidation ratio, coefficient of earth pressure at rest and stiffness. It can also give an indication of soil type and has the ability to act as a profiling tool. Potentially this is a very powerful insitu testing device.

2. The test relies entirely on empirical correlations developed by Marchetti for Italian soils (ref. 1); the Building Research Establishment (BRE) has been using the dilatometer for about three years in order to assess the device and its test reproducibility, as well as the validity of the correlations for a range of different UK soils (refs. 2 & 3). The dilatometer has been used on well documented UK test sites where reliable reference soil data are available.

3. This paper reviews the earlier work undertaken by BRE to examine the use and effectiveness of the device and, with the aid of additional data now available, gives revised guidance on interpreting the results for UK clays.

DILATOMETER TESTING.

4. The dilatometer is a stainless steel blade 250mm long, 94mm wide and 14mm thick with a tip angle of about 16° (fig. 1). One face of the blade is recessed to take a 60mm diameter stainless steel membrane which lies flush with the face of the blade (ref. 1).

5. Tests are performed every 200mm down a profile with the blade being advanced at 20mm/sec between tests. At each test level the driving load is removed and a regulated gas pressure applied to inflate the membrane. Electrical sensors behind the membrane indicate the start of movement and 1mm displacement, when gas pressures p_0 ('lift off') and p_1 respectively are recorded. A recent suggested modification (refs. 3 & 4) to the test procedure has been to record, in addition to p_0 and p_1, the closing pressure (p_2), the point at which the membrane returns to the 'at rest' position as the gas pressure is slowly released. Full details of the installation and test procedures used by BRE can be found in ref. 2.

6. Marchetti suggested that three index parameters, Material index I_D, Horizontal stress index K_D and Dilatometer modulus E_D could be derived from the test. These are determined from the contact pressure, p_0, and the 1mm expansion pressure, p_1, together with a knowledge of the insitu porewater pressure and the bulk density. The index parameters are then used empirically to obtain the various soil properties.

7. The variation in soil type down a profile is related to the Material index I_D and particularly to the soil particle size; I_D is determined from:

$$I_D = (p_1 - p_0) / (p_0 - u_0)$$

8. The Horizontal stress index K_D is determined from the expression:

$$K_D = (p_0 - u_0) / \sigma'_{vo}$$

where u_0 = insitu porewater pressure before insertion,

σ'_{vo} = effective overburden pressure.

K_D is then empirically related to the coefficient of earth pressure at rest K_o; it is also used in the estimation of the overconsolidation ratio OCR and the undrained shear strength c_u.

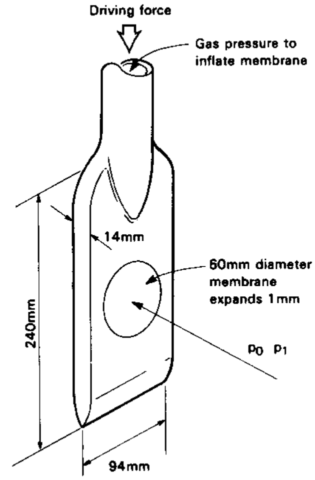

Fig. 1. Sketch of Marchetti dilatometer blade.

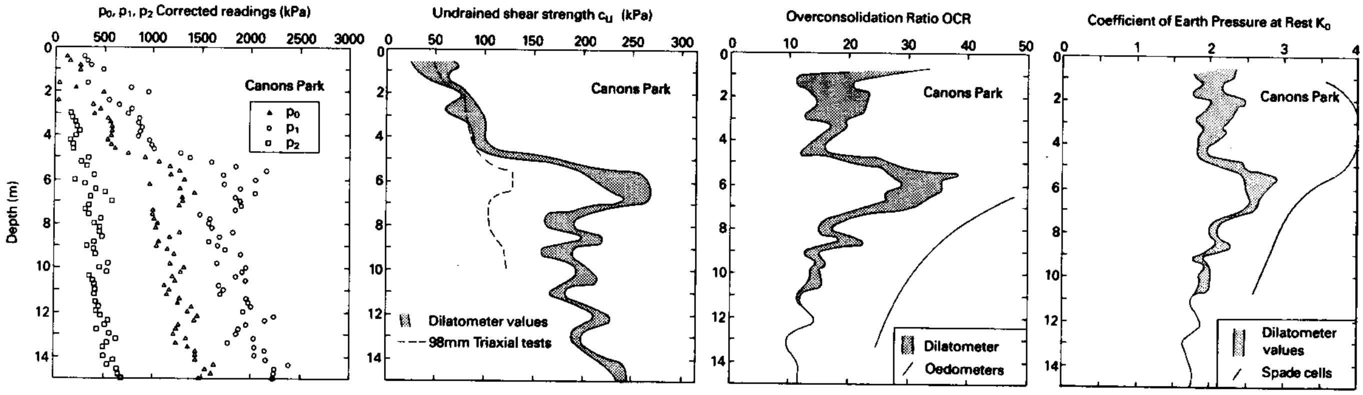

Fig. 2. Geotechnical parameters - Canons Park.

9. The Dilatometer modulus E_D is determined from the expression:

$$E_D = 34.6 (p_1 - p_0)$$

E_D is empirically related to the modulus of elasticity of the soil. It is said to be representative of the stress/strain curve during the 1mm expansion of the membrane.

10. The initial relationships determined by Marchetti have been used throughout this work and the resulting soil properties have been compared with the reference properties determined for the various sites.

TESTS RESULTS

11. Typical results are considered by reference to two test bed sites used by BRE; the first is a stiff London clay site at Canons Park, North London, and the second is a soft alluvial clay at Grangemouth, Scotland. Details of these two sites, and others mentioned later, are summarised in refs. 3 & 5.

12. In figs. 2 and 3 the processed pressure readings p_0, p_1, p_2 are plotted against depth and follow very similar shapes to the cone resistance profiles for the two sites (refs. 5 & 6). The scatter in the pressures from several profiles was very small; more detailed plots from other BRE stiff clay sites are given in ref. 2. The very reproducible nature of the test results has now been reported many times (refs. 2,3,7 & 8).

13. The soil properties of K_o, OCR and c_u, determined from the pressures p_0 and p_1, via the index parameters and Marchetti's correlations, give fairly reproducible profiles for each site (figs. 2 & 3). It should be noted that whilst the profiles of p_0, p_1 and p_2 are from a single test profile, those for the deduced parameters are the envelopes from at least 4 profiles.

14. For the London clay at Canons Park (fig. 2), the DMT results, using Marchetti's correlations, significantly underestimate the reference values for OCR and K_o but give approximately the right shape of variation down the profile. This result is consistent with results from other stiff clay sites (London and Gault clays, ref. 2). There is good agreement for the shear strengths in the upper deposit (fig. 2), which is glacially reworked London clay, to a depth of about 4m. Below this depth the DMT significantly overestimates the strengths in the weathered and unweathered clay but again shows roughly the right shape. This observation will be discussed in more detail later.

15. For Grangemouth (fig. 3) the undrained shear strength, derived from the Marchetti correlations, is in good agreement with triaxial strengths although slightly below the values obtained from the self boring pressuremeter (SBP). However the K_o and OCR values are both overestimated although the variation down the profile is approximately correct.

16. The two examples above indicate that whilst the DMT gives profiles of c_u, K_o and OCR of similar shape to the reference values, there can be significant over and underestimates of the actual values by the DMT with only the shear strength at Grangemouth being well reproduced. These results suggest that the correlations used to convert the DMT data to soil properties are not correct; Powell and Uglow (ref.3) indicate that site specific correlations appear to exist for the sites investigated.

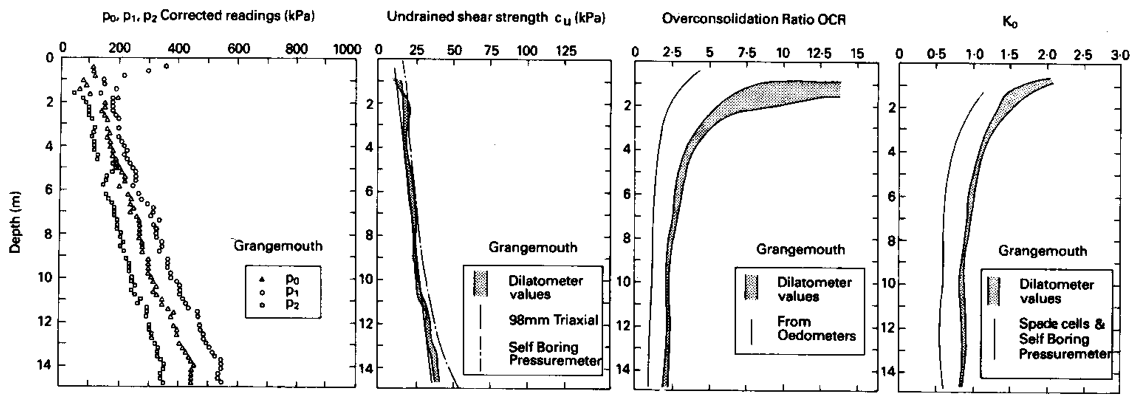

Fig. 3. Geotechnical parameters - Grangemouth.

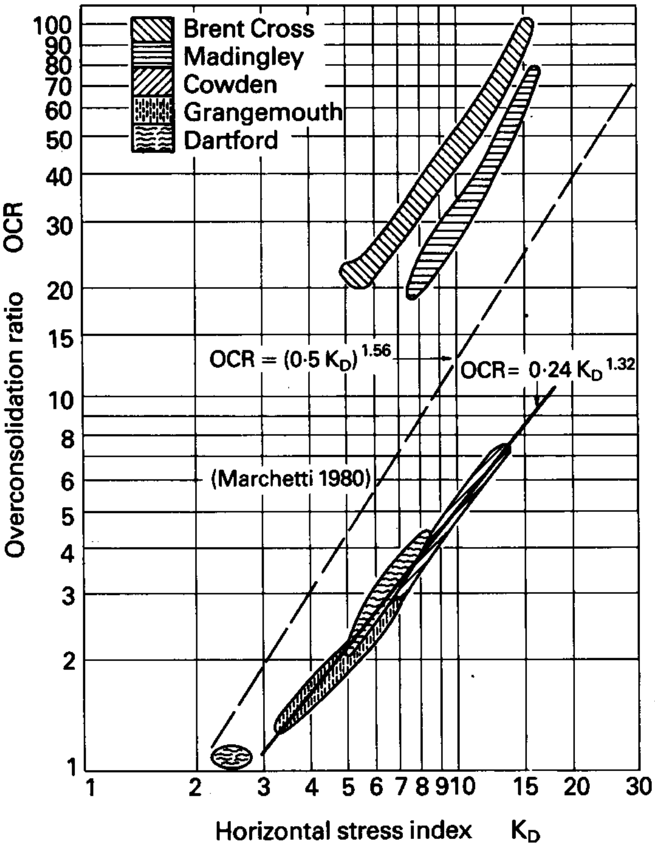

Fig. 4. Overconsolidation ratio verses horizontal stress index K_D.

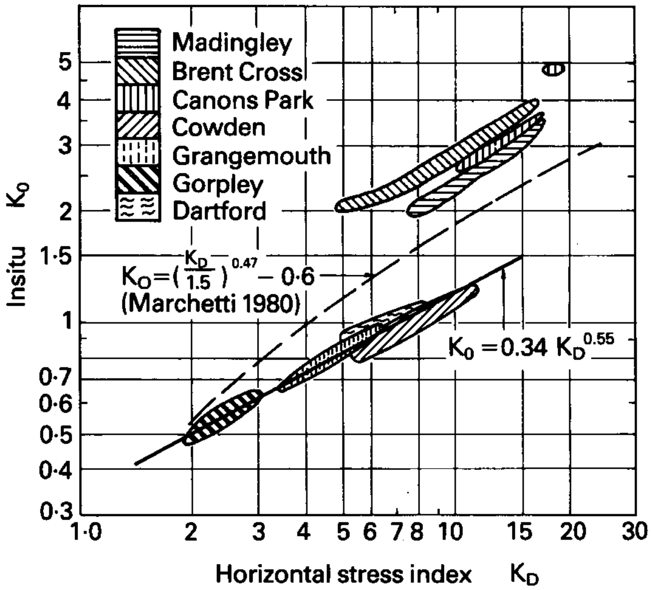

Fig. 5. Insitu K_o verses horizontal stress index K_D.

17. The issue of the correlations is now considered in more detail, by reference to a number of UK sites, by using similar plots to those originally used by Marchetti.

OCR and K_o

18. Figs. 4 and 5 show respectively the variations of OCR and K_o with K_D, the horizontal stress index; also shown are Marchetti's correlation lines, the equations of which are used to deduce OCR and K_o from K_D. The primary source for reference OCR values has been oedometer data, whilst values of horizontal stress to derive K_o have come from total stress spade cells, the self-boring pressuremeter and some suction tests. In addition secondary assessments of K_o have been made from OCR (ref. 9) and vice versa.

19. It is clear from figs. 4 and 5 that the UK data do not coincide with the Marchetti lines. As discussed in earlier publications (refs. 2 & 3), strong site specific correlations appear to exist; however with these latest plots, containing additional data, it is evident that there is a pronounced grouping of the site specific correlations. In both figures, data from the soft clay sites (Grangemouth, Dartford, Gorpley) and the stiff glacial clay tills at Cowden, show a very strong grouping. The heavily overconsolidated clay data (Canons Park, Brent, Madingley) plot as a separate group without such tight overall grouping, but show strongly individual trends closely parallel to Marchetti's lines. It should be noted that it is very difficult to get meaningful values of OCR from oedometer tests on very stiff, highly overconsolidated clays, unless they are taken to the virgin compression line.

20. A detailed analysis of all the data has led the authors to conclude that the marked differences in age that exist between the clays studied could be a major factor. Clays in the lower group in figs. 4 and 5 are younger than 70000 years Before Present (BP), whilst the upper group clays are all older than 60 million years BP and have probably been subjected to a much more complicated stress history with possibly significant ageing.

21. As a result it is suggested that:

i) for "young" clays the DMT results are interpreted using the following correlation equations;

$$K_o = 0.34\ K_D^{0.55}$$

and

$$OCR = 0.24\ K_D^{1.32}$$

ii) for "old" clays; either

a) use has to be made of existing experience on that soil type to establish a correlation,or

b) if some information on K_o and OCR is known for the site (1 or 2 values) then these should be plotted against K_D on figs 4 and 5 and a new correlation line drawn through them parallel to the Marchetti line. The correlations in (i) above are very similar to those derived by Lacasse and Lunne (Ref. 8) in parallel work at the Norwegian Geotechnical Institute (NGI).

Shear strength c_u

22. Fig. 6 shows the undrained shear strengths from 98mm diameter triaxial samples, normalised by the effective overburden pressure, plotted against K_D. They are seen to plot around the Marchetti line in the case of the "young" alluvial and glacial clays as well as the reworked London clay at Canons Park. The "old" clays from Brent and Canons Park are seen to form correlations that are roughly parallel to the Marchetti line though significantly displaced from it; this is consistent with fig 2. The "old" Gault clay at Madingley fits the Marchetti line well but is based on 38mm diameter triaxials which could explain the

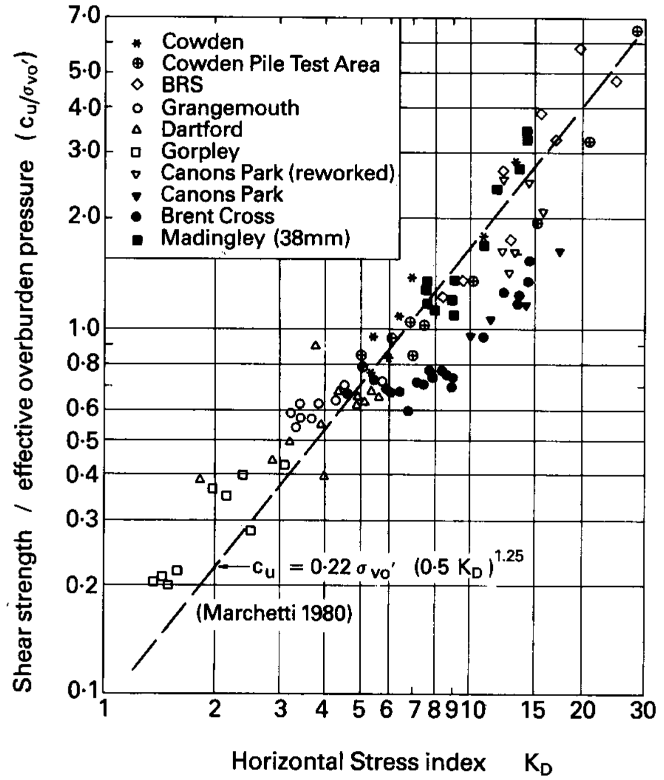

Fig. 6. Shear strength/effective overburden pressure verses horizontal stress index K_D.

apparent agreement (lower strengths are usual in Gault clay when 98mm samples are tested, due to fissuring and fabric features)

23. It is suggested that to assess the equivalent 98 mm triaxial strength then:

(i) for "young" clays the Marchetti correlation line can be used, remembering that a slight displacement from this line on a log/log plot can yield significant errors.

(ii) For "old" clays it is suggested that, either

(a) existing data or correlations for that soil type can be used, or,

(b) given limited new data, a line parallel to the Marchetti line can be drawn through the known data. This procedure may not work once macrofabric scale effects become significant.

24. Different conclusions and correlations will result if the reference shear strengths are derived from different tests eg. simple shear, vane, 38mm triaxial etc. (refs. 4 & 8)

Soil identification and density

25. Marchetti suggested (ref. 1) that soils could be classified in terms of type, unit weight and consistency, based on their position on a chart of E_D verses I_D. The BRE experience is that the chart has mixed success in identifying certain soil types and their densities (ref. 3).

26. All material studied so far would plot above the Casagrande A line and would therefore be described as clay. In fig. 7 the Cowden and Gorpley soils have almost equal amounts of clay and silt size particles and are correctly described as silty clays or clayey silts. The Gault at Madingley and the London clay at Brent and Canons Park have clay contents in excess of 60%, but these also fall on the clay/silt

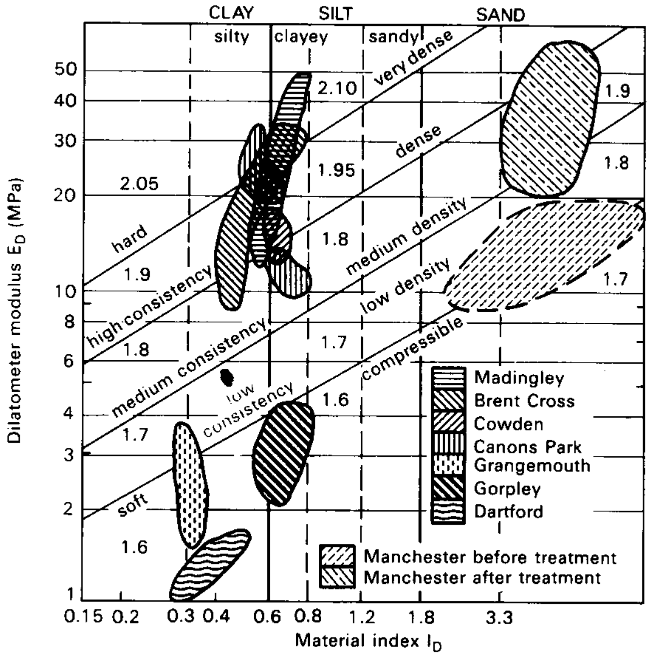

Fig. 7. Soil classification: E_D verses I_D.

border. It is thought that the very high degree of overconsolidation and the relative age of these soils may be affecting the material index derived for these deposits.

27. From a comparison between known unit weights and those assessed from the DMT, it can be seen in fig. 8, that the DMT tends to underestimate the values. Further, a disproportionately large increase in the assessed unit weight is recorded for a small increase in actual unit weight. However the DMT does indicate the variations in unit weight, if overemphasising them.

Soil stiffness.

28. Marchetti (ref. 1) correlated the dilatometer modulus E_D with the constrained modulus ($1/m_v$ or M) obtained from oedometer tests. This may seem odd as the dilatometer test is considered undrained in clays whilst the

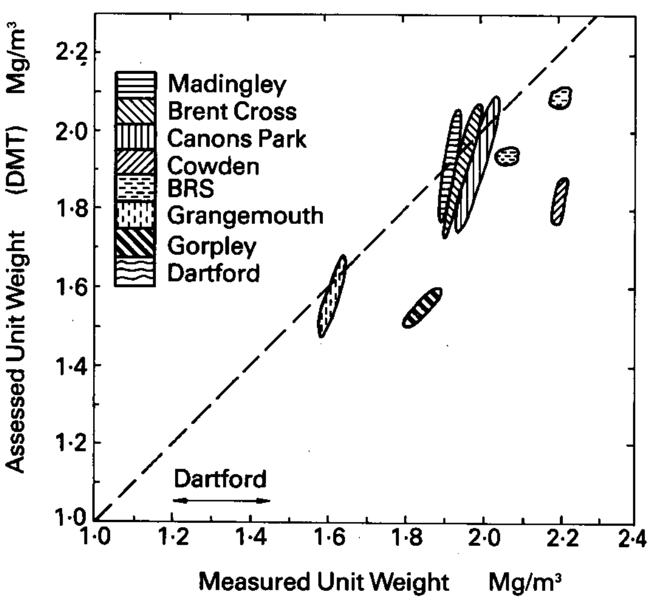

Fig. 8. Comparison of measured and assessed unit weights.

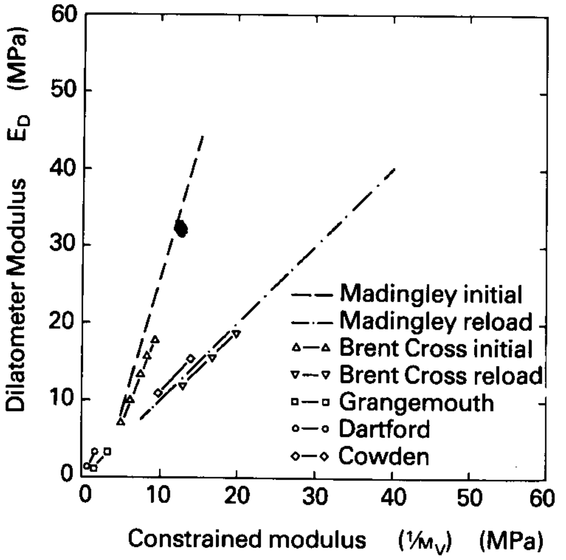

Fig. 9. Constrained modulus verses dilatometer modulus E_D.

constrained modulus from an oedometer test is for the drained case. Even so, empirical correlations with the constrained modulus from the drained oedometer test have been preferred because of their use in settlement predictions. As mentioned by Lacasse and Lunne (ref. 8), the dilatometer expansion is effectively at large strains so again it seems unlikely that any small strain undisturbed value could be obtained. In refs. 2 & 3 it is stated that no correlation had been found, from the limited data on UK soils, between E_D and constrained or shear modulus. However additional high quality oedometer tests have been performed on samples taken from some of the UK sites, and as shown in fig. 9. There are now clear linear trends between E_D and $1/m_v$ for several sites. The relationship changes depending on site and on whether initial or reload values are considered. It is worth noting that Marchetti and others (refs. 1, 4 & 8) obtained the constrained modulus from the DMT by using the relationship:

$$M = R_M \cdot E_D$$

where M = constrained modulus,
E_D = dilatometer modulus,
R_M is a scaling factor,

It has been suggested (refs. 1, 4 & 8) that for clays, R_M is typically 2-3; however, in fig 9, R_M (the slope of the lines) would be ≤ 1.0, so this still needs further investigation. It is suggested at this stage that it would be necessary to establish individual correlations between E_D and M for particular soil types. Others have attempted to correlate between E_D and the elastic modulus of the soil (ref. 8), however no satisfactory correlations have yet been found in UK soils.

CONCLUSIONS.

29. The DMT produces very repeatable profiles for each site and in this respect a high degree of confidence can be placed on the device. In many cases Marchetti's original correlations do not appear to hold for the soils investigated and distinct differences in correlation have been found between "young" clays (<70,000 years) and "old" clays (>60m years).

30. Recommendations have been given for these two groups for assessing the undrained shear strength, overconsolidation ratio and the coefficient of earth pressure at rest. The recommendations for the undrained shear strength correlation are based on strengths determined from triaxial tests on good quality 100mm diameter thin wall push or piston samples.

31. More work is needed to improve the soil density and description charts. In general the DMT picked up the changes in soil type and unit weight although the actual values need correction and refining.

32. Now that more applicable correlations are becoming available it is concluded that the DMT will have a more significant role to play as a profiling tool that is able to provide useful information on a wide range of soil properties.

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