The Clay Research Group

Site Investigation

and

Soil Testing

Soil Test Comparisons using Disturbed and Undisturbed Samples from the Aldenham Research Site

by

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The Clay Research Group

www.theclayresearchgroup.org

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Investigations and Soils Analysis

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INTRODUCTION

- Soil Sampling and Testing -

There has been much debate over recent years surrounding the accuracy of testing soils to detect desiccation. Richard Driscoll provided some very useful guidance when he developed a relatively simple test allowing engineers to make an approximate assessment based on comparing the moisture content of the soil with their Plastic and Liquid Limits.

Mike Crilly and Prof. Richard Chandler sought to improve on this about 10 years ago when they introduced the filter paper suction test to the subsidence market. Measuring negative porewater pressure has always been recognised as a superior method of determining desiccation, but prior to the development of this test, the costs were prohibitive. In addition, measuring suctions in excess of 100kPa is beyond many of the more commonly used devices.

Questions arose about the reliability and repeatability of the filter paper test. Research at Imperial College by Andrew Ridley (using the suction probe) suggested that the filter paper test might be vulnerable to delivering anomalous readings due either to variations in the filter paper or the soil mineralogy – in particular in soils with high salt concentrations – or a combination of the two.

The oedometer measures swell direct, but has relied on retrieving undisturbed samples, the cost of which has been beyond the insurer's budget when investigating predominantly low value domestic subsidence claims.

The purpose of this research was to try to understand the relative 'accuracy' of the various tests, and the influence of sample disturbance using the research site in Aldenham.

The work was entirely funded and undertaken by MatLab Limited, a specialist, UKAS accredited soil testing laboratory in the West Midlands.

THE SITE

Aldenham School occupies a 100 acre site to the North West of London, within the M25. The Clay Research Group (CRG) were granted access to monitor and investigate the ground in the vicinity of two mature trees, an Oak and a Willow.

The Oak site is reasonably level. The Willow occupies a site that slopes by about 5 degrees.

Reference to BGS mapping confirms the geology to be predominantly outcropping London Clay with Woolwich & Reading Beds of the Lambeth Group to the North West and undifferentiated drift to the North.

Drift deposits, mainly sands and gravels with some silt, were encountered in several locations in the vicinity the Oak. Gravels were encountered for the full depth of the bore when sinking the Datum at Station 10 and in the hole sunk for Neutron Probe 3.

The London Clay series was fairly consistent on the site of the Willow. <u>For this reason we have restricted this report to the results from this location. The Oak samples have been discarded.</u>

See Figure b1 (following page) for a plan of the site showing the location of the boreholes and level stations.

SAMPLING

Bores were sunk to 5mtrs bGL and samples were retrieved at 500mm ctrs intervals from the sites of the Oak and Willow at Aldenham prior to being sealed and delivered to the laboratory.

Only disturbed samples are available from the May 2006 investigations. Both disturbed (50mm diameter - D50 – hand auger) and undisturbed samples (undisturbed 100mm diameter - U100 – driven sampling tubes) were retrieved in June 2007.

SOIL DESCRIPTION

The geology on the Willow site is typical of the London Clay series and the laboratory description is “a soft/firm/stiff brown clay with rare silt veinings and very fine gypsum”. The Plasticity Index is in the range 30 – 55% with the lower values at shallow depth. The soil fall predominantly into the high shrink/swell category.

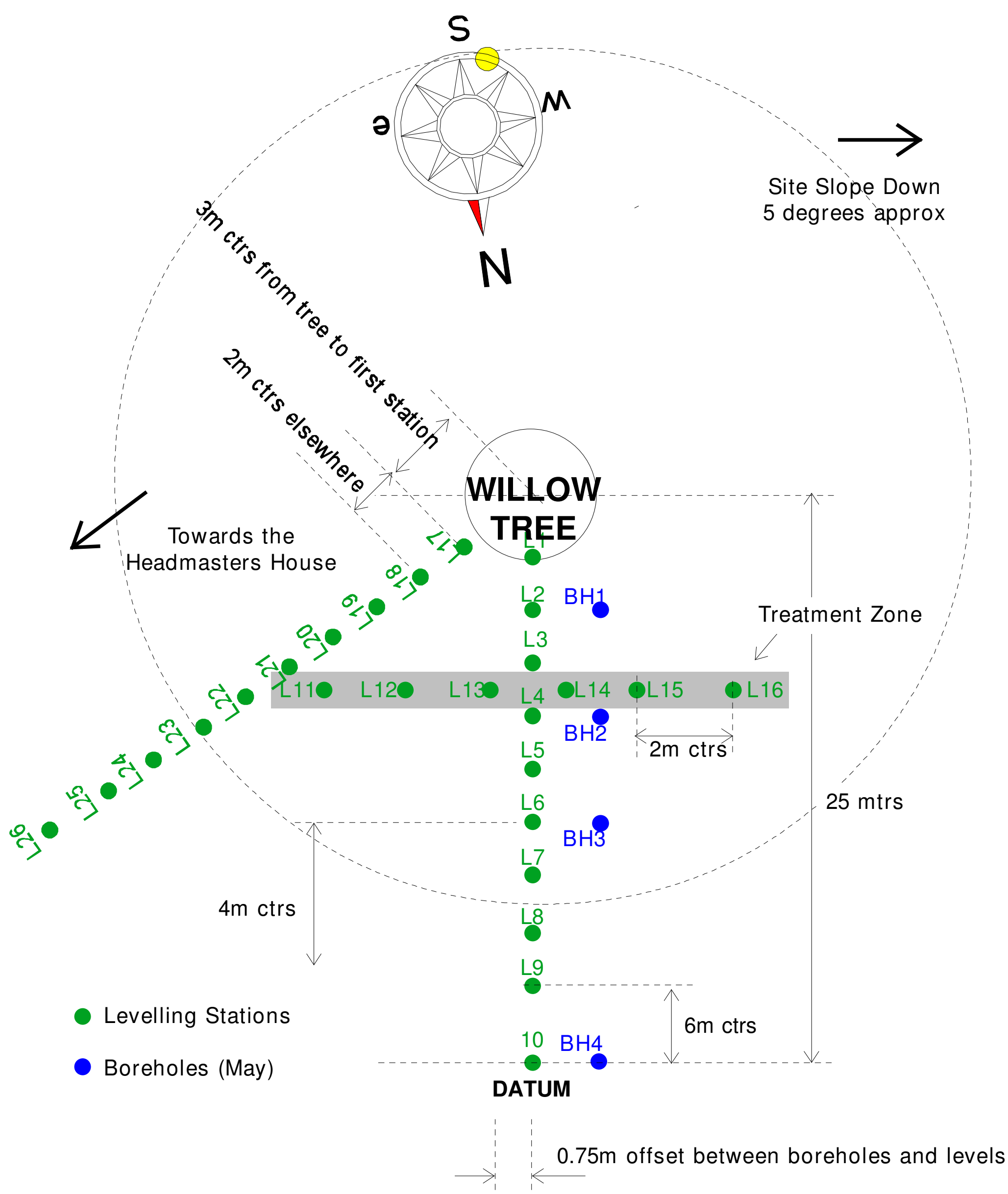


Figure 1
THE SITE

Level monitoring stations (green) and boreholes (blue).

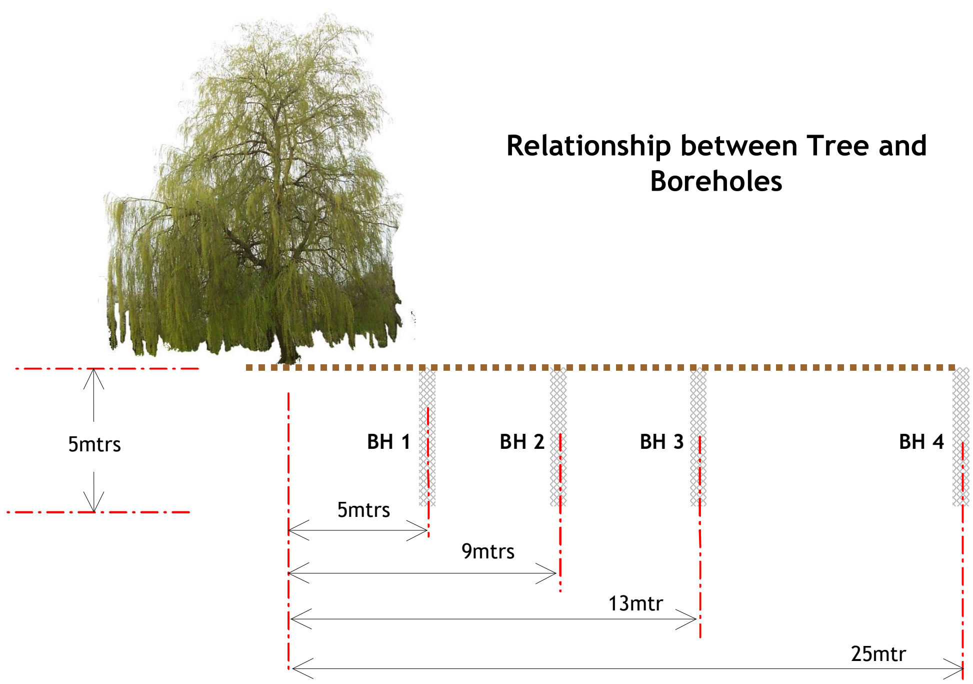


Figure 2
Borehole Locations

LABORATORY ANALYSIS

Strains were obtained for samples from all bores using the oedometer, and for suctions using the filter paper test. The laboratory determined the moisture content and the Liquid and Plastic Limits of the soil, and provided a description.

Two filter paper tests were obtained for every 500mm length of sample from the June 2007 results, disturbed and undisturbed. That is to say, we have two comparative suction test results for each sample.

They are noted as Test_1 and Test_2.

TEST RESULTS

The most reliable estimate of desiccation is provided by the undisturbed oedometer test. Although not without problems in terms of extraction, testing etc., this test has been widely used over many years and is the standard by which we judge the alternative test methods.

OEDOMETER TEST

The test involves placing samples of clay into a cell and consolidating them to their estimated in-situ stress in accordance with a technique developed by MatLab and agreed and accredited by UKAS under Certificate MTLB002. Distilled water is added to the cell and the resulting strains are measured using calibrated equipment. The following assumptions have been made. (1) Soil Bulk Density (Moist Unit Weight) is equal to 2039kg.m^3 (2) the water table is assumed at 1.0m below ground level and (3) a shrinkage factor (Sf) of 2 has been applied to the predicted heave value. The testing has been undertaken in accordance with BS1377:Part1:1990 (sample preparation and calibration of equipment) and BS1377:Part5:1990 - Section 3 & 4.4 (use of equipment and testing technique).

FILTER PAPER TEST

A review of testing for desiccation in clay soils can be found in B.R.E. Digest 412, published in February, 1996. Refer also to Chandler , Crilly and Montgomery-Smith (1993) "A Low Cost Method of Assessing Clay Desiccation" Proc.Inst.Civ.Eng.

GRAVIMETRIC MOISTURE CONTENT

The samples have been weighed before and after oven drying to measure the gravimetric moisture content. The line of the equivalent Mc (blue) has been superimposed onto the Plasticity Index envelope described by the Plastic and Liquid Limits. Equivalent moistures, factored to take account of the "% passing" value, have been used throughout.

INDEX PROPERTIES

The PL and LL envelope is represented as a shaded polygon onto which the moisture content has been superimposed. Soils with a Plasticity Index below 20% are regarded as having low shrink swell potentials, whilst those between 20-40% medium, and above, high. The soils tested were predominantly in the high shrink/swell potential category.

NEUTRON PROBE DATA - VOLUMETRIC

Neutron Probe Data is only available for the Oak site - no readings are available for the Willow.

CLIMATE

2007 was a wetter year than 2006, with heavier than normal rainfall. See Fig. 4 for comparison data. The precise levels in the vicinity of the Aldenham Willow are plotted below and the recovery profile in 2007reaffirms this – Figure 3.

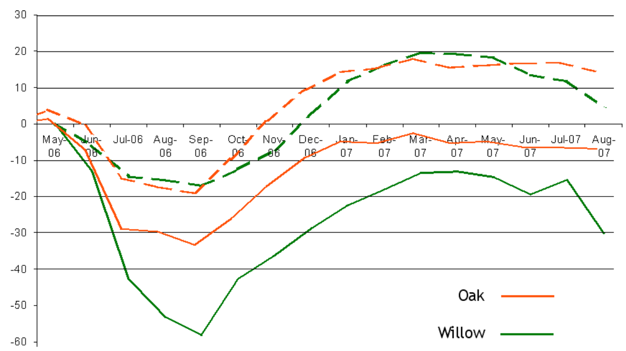


Figure 3
The precise level readings plotting ground movement from May 2006 through to June 2007.

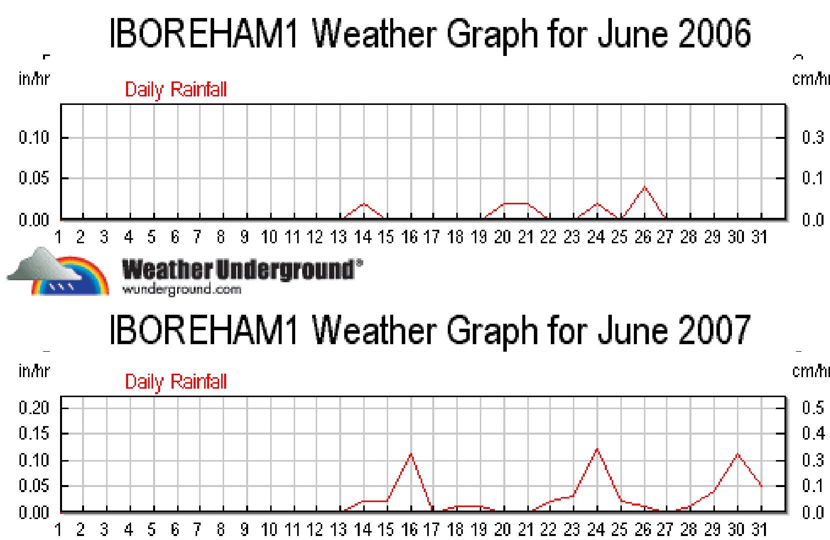


Figure 4
Rainfall comparisons, June 2006 and 2007

OEDOMETER TEST RESULTS

The oedometer is a reliable method of assessing desiccation when using undisturbed samples. The results from Aldenham are reproduced below (Fig 5) and act as the bench-mark against which other tests are compared.

It can be seen that root induced desiccation diminishes across the site, reducing with distance away from the tree.

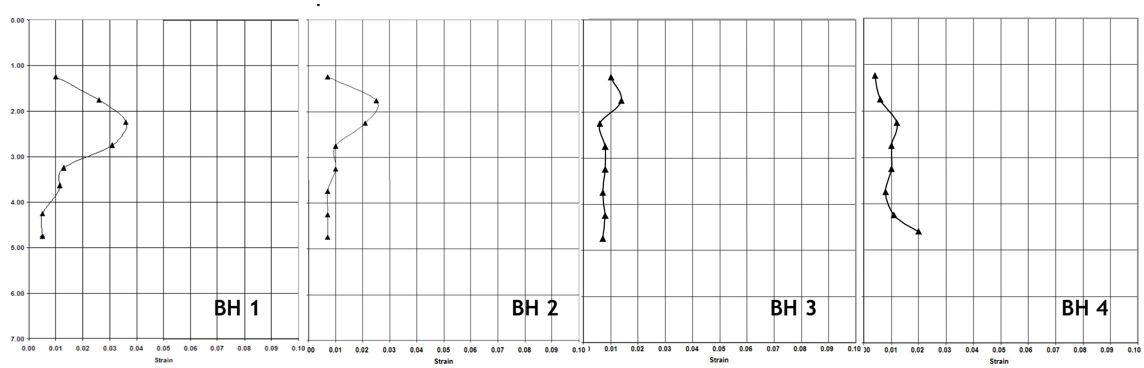


Figure 5
Oedometer Undisturbed Sample, June 2007.

Below, Figure 6, disturbed data are plotted as a broken line – they are plotted alongside the undisturbed samples. There is little to distinguish between the results in terms of peak strain values and zones of desiccation. The form of the plots is uniform with little scatter. There is no drift at lower levels – the values return to an undesiccated profile as we would expect.

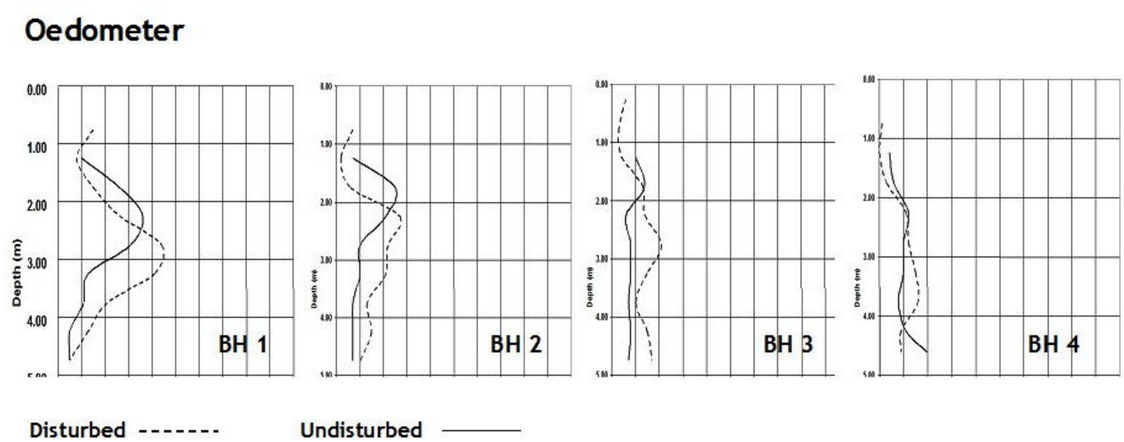


Figure 6
Oedometer Disturbed and Undisturbed Samples, June 2007

OEDOMETER TEST RESULTS - 2006

Below (Fig 7) we have superimposed the results of the disturbed sampling from May 2006 (red line) to show the effect of rehydration.

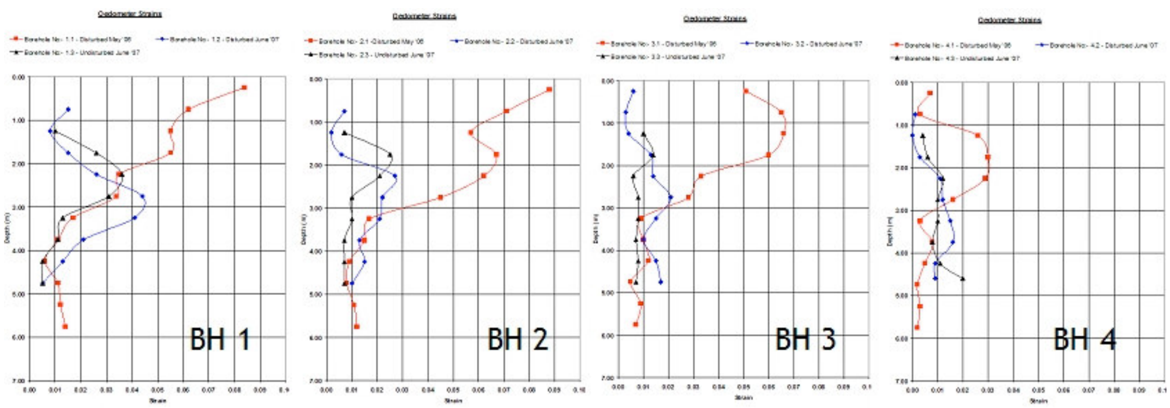


Figure 7
Oedometer Disturbed (May 2006) and Undisturbed Samples, June 2007.
Note the dissipation of strains over the 13 month period. See Figure 8 for
A more detailed explanation.

The oedometer is a reliable test and there are advantages in measuring swell directly. Although undisturbed samples are preferred, for routine domestic claims we see little loss of accuracy when using disturbed samples.

The test identifies desiccation where it exists, and appears to provide a sensible estimate of strains.

OEDOMETER - Rehydration Between 2006 & 2007

The effect of rehydration following rainfall can be seen below – the blue shaded zone. The red line represents the May 2006 profile. By June 2007 the upper portion of soil had started to recover, leaving a zone of desiccation peaking at 3mtrs bGL. BH 1 is enlarged below for explanatory purposes.

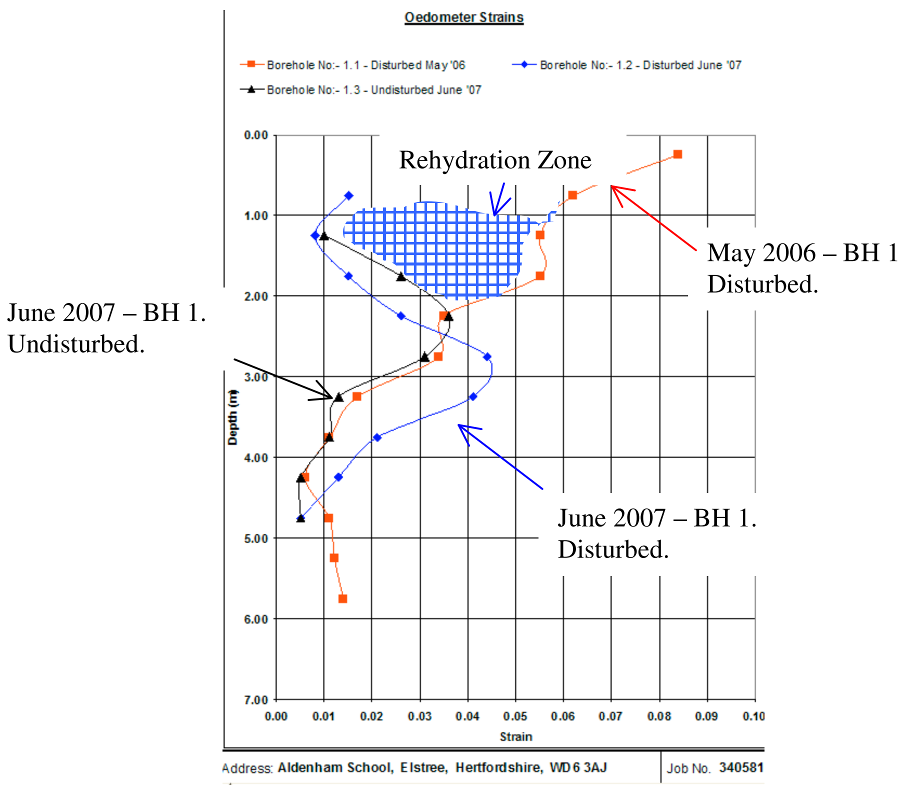


Figure 8
Enlarged Plot of Oedometer Results from BH 1

The data are entirely consistent with the weather conditions in 2006 and the change that we would anticipate following twelve months of higher rainfall. The relative strains across the root footprint are characteristic of root induced desiccation, diminishing with distance from the tree as we have seen in earlier studies by Biddle, Ward and at Chattenden.

Equivalent Moisture Contents

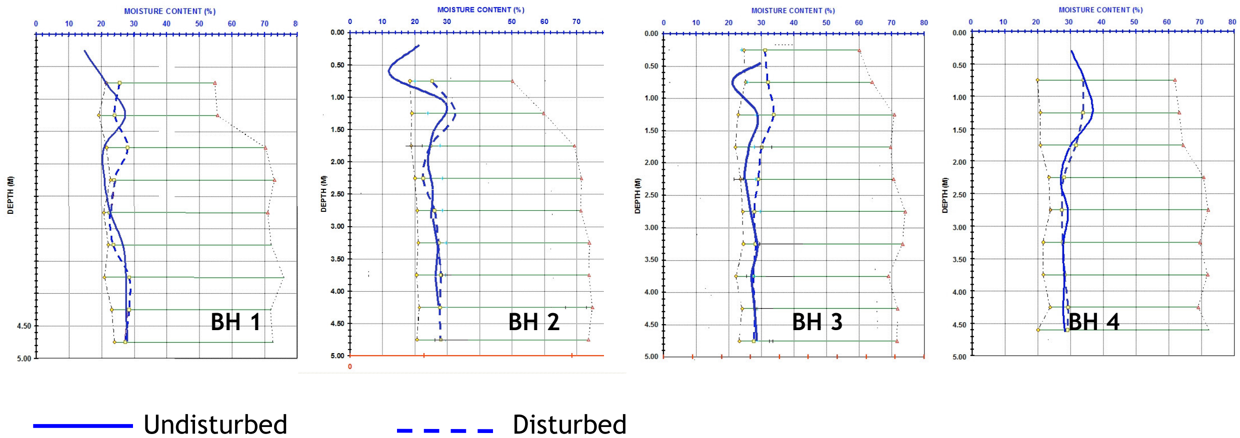


Figure 9
Moistures Content Profiles plotted onto the index envelope. June 2007 data.

The natural moisture contents for both undisturbed and disturbed samples are plotted above, for each of the bores. We have used the Equivalent Moisture Content, taking into account the "% passing" value.

The undisturbed samples generally have lower values, but not always. Plotting the disturbed and undisturbed values alongside one another reinforces the issue surrounding the detection of desiccation using moisture contents alone.

This problem has led to various techniques to interpret the data, including the Liquidity Index and the approach proposed by Richard Driscoll. These are explored in the following pages.

COMPARING Mc WITH SOIL INDEX PROPERTIES

This method, proposed by Richard Driscoll (Driscoll R. (1983) "Influence of Vegetation on Clay Soils" Geotechnique. Vol. 33), seeks to establish a relationship between the moisture content and index properties of the soil. Richard suggested that a soil might be desiccated if the moisture content is **less** than (a) 0.4 x LL or (b) 2% above the PL.

Richard preferred the LL test as the more reliable of the two and recommends this assessment is always used in conjunction with one of the other forms of testing.

Below we compare the Equivalent Mc (solid lines) with 0.4 x Liquid Limit (red broken line) and Plastic Limit + 2% (blue broken line) for the June 2007 undisturbed samples.

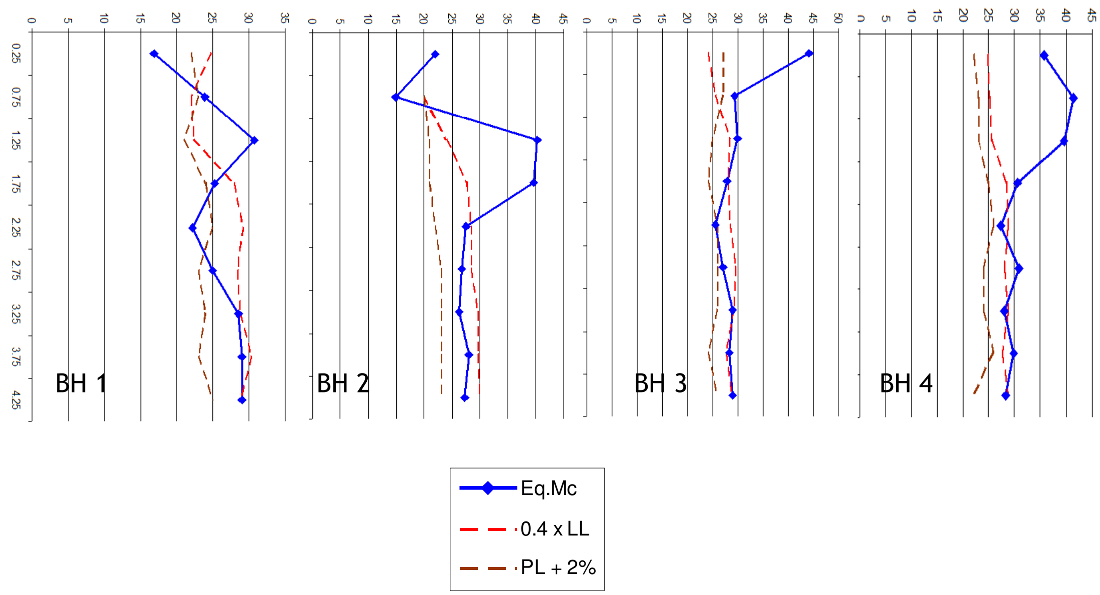


Figure 10
Moistures compared with the Driscoll parameters. June 2007 data.

We have noted that the moisture content increases just above the zone of desiccation - where it exists. The relationship between the moisture content and the index properties from 3mtrs down is less clear. Although it may appear that there is a deficit it is the natural state of the soil, reflecting the in-situ stress.

As mentioned before, changes in moisture content sufficient to cause movement can be quite small and therefore difficult to detect. Above we see very little difference across the range apart from at BH 1 where desiccation, peaking at 2.25mtrs bGL, is easily identified.

LIQUIDITY/CONSISTENCY INDEX

The Liquidity (or Consistency) Index is the normalised value of the moisture content on a scale between PL = 0 and LL = 1.

$$LI=(Mc-PL)/(LL-PL) \quad \ldots\ldots \text{ normalisation formula}$$

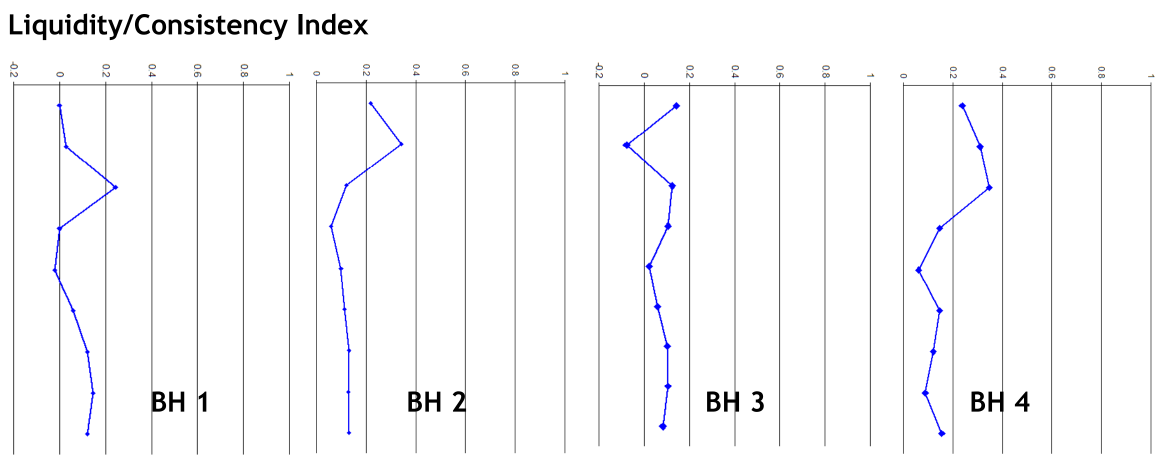


Figure 11
Liquidity Index relationships for all boreholes. June 2007 Undisturbed Samples.

When using this method of interpretation a value of '0' suggests a desiccated soil and '1' a saturated soil. BH 1 provides the clearest evidence of desiccation using this method. Elsewhere the relationship is discernible, but less obvious. This isn't surprising at it relies on moisture content determinations as mentioned before.

As described before (see previous page) there is often a saturated soil immediately above a zone of desiccation and moisture content return to the equilibrium levels (around 30% Mc) beneath it. In common with all other tests, the zone of desiccation lies at around 2mtrs bGL.

FILTER PAPER SUCTION TEST

There is a wide range of data from the undisturbed –v- disturbed filter paper results and the disturbed data showed more scatter. In addition, there were problems with lateral drift with depth, which is particularly evident in the Test_2 results. The so-called 'increasing linear suction' anomaly is illustrated in the Test_2, BH 3 data. MatLab report seeing this often – possibly in around 20% of the reports they produce.

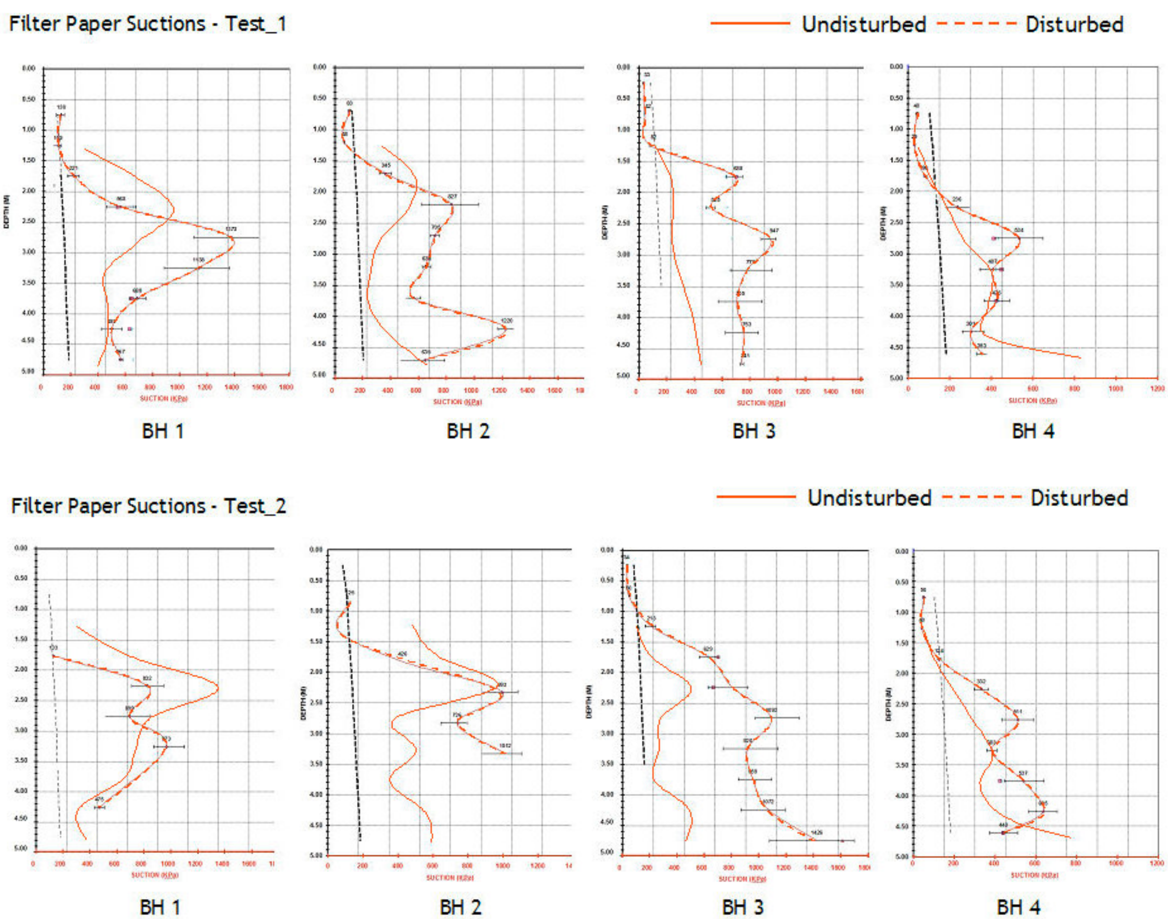


Figure 12
Filter Paper Suction Tests . June 2007 Disturbed and Undisturbed Samples.

From the results it would appear that sample disturbance can lead to an over-estimate of desiccation using the filter paper test.

FILTER PAPER SUCTION TEST

Below are the filter paper suction results from both disturbed and undisturbed samples from the June 2007 investigation. The results illustrate the variation between the samples – the spread between disturbed and undisturbed.

Filter Paper - Combined - June 2007

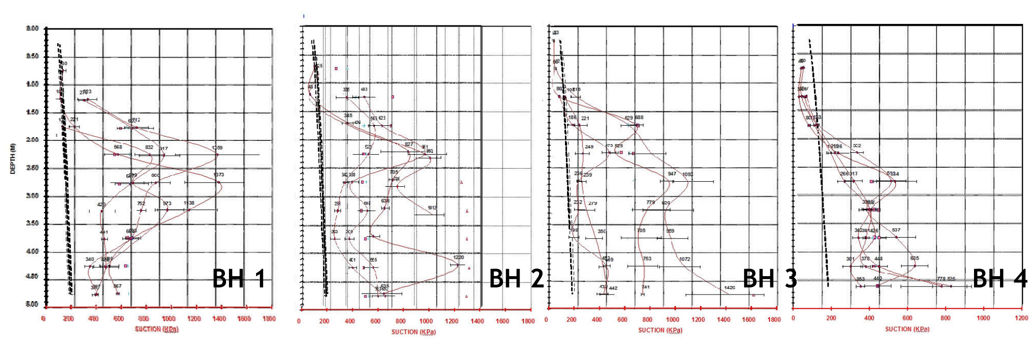


Figure 13
Envelopes of filter paper test data for each of the boreholes at the Willow site enclosing all of the results (both disturbed and undisturbed).

The differences between 'all samples' is quite large – see graphs above – when compared with the oedometer data. In addition we see drift at depth with the suctions rarely returning to the postulated Ko line.

In BH 3 the drift is indicative of an anomalous result possibly associated with soil mineralogy.

RESULTS - DISCUSSION

OEDOMETER

Undisturbed oedometer test results are probably regarded as the bench-mark for detecting desiccation. The U100 samples have produced profiles that are 'regular' in form with values diminishing with distance from the tree. See Appendix for the results.

1. There is little, if any, lateral drift-over-depth of the sort we have seen using the filter paper method.

2. The desiccation 'bulge' is easier to detect than when using moisture contents.

3. There is good correlation between disturbed and undisturbed samples. Both produce similar patterns. The disturbed samples did not produce significant scatter.

Estimates of swell produced using the oedometer would be improved (that is, reduced) by discounting strains less than 0.01 at high strains. As an example, in this study, the estimates for all tests (May 2006 and June 2007, disturbed and undisturbed) would have been reduced by nearly 20mm.

GRAVIMETRIC MOISTURE CONTENT

The requirement to detect small changes in Mc reduces the usefulness of the test, which reinforces the comments made in BRE Digest 412. A decision as to whether a soil is desiccated or not relies on a change in the moisture content of a few percentage points only.

Confidence in determining desiccation reliably, every time even with low suctions, using this technique alone, is low. It does have use as a secondary 'validation tool' when assessing apparently anomalous filter paper test results. Vertical moisture contents at or around 30% combined with high linear suctions, increasing with depth, are indicators of a problem with the filter paper test results.

In our view, and having consideration for results both from this study at Aldenham and elsewhere, moisture may afford a supplementary clue to assist in the determination of desiccation when there is a saturated clay overlying a zone of dry soil. This is often a sign that the soil is, or has recently been, desiccated. It will only be useful when there is a suggestion of underlying desiccation. Saturation alone would be insufficient.

INTERPRETATION TECHNIQUES

Both seek to resolve the problem described above. Neither performed well, and the output may fuel debate between contesting parties than resolve it.

FILTER PAPER TEST

1. Interpretation is reliant on identifying where the Ko line lies – see Appendix B for an explanation of this. We should not assume that the values suggested by Crilly and Chandler can be rigidly applied. Sample disturbance appears to lead to lateral 'drift' of the suction profile with increasing depth and some adjustment may be required. See Fig 14 & 15.

2. In general (but not always) sample disturbance produces more 'scatter' and a sometimes irregular plot. BH 2 illustrates this well. Both U100 profiles show a clear root induced suction bulge peaking at around 2mtrs bGL with the plot below falling back to align with the Ko profile. In contrast, the disturbed samples are irregular, drifting laterally with depth. The wide range of results has led MatLab to undertake further research into the use bentonite pellets to replace the filter paper altogether.

3. As a result of the above, disturbed samples appear to lead to an over-estimate of swell potential when compared with other methods, partly due to this lateral drift at depth as we see in BH 3.

4. In BH 4 we see possible evidence of under-draining in the undisturbed samples, commencing below the zone of root activity whereas the disturbed profiles might suggest tree root activity.

DISCUSSION

This is a limited study of a particular soil in the vicinity of a unique tree over a specific period of time. However, the results provide few surprises to the experienced practitioner and highlight some acknowledged issues.

First, precise levels have recorded ground movement associated with moisture change in the underlying clay soil over an eighteen month period and we can be confident the soils have, at some stage, (a) been desiccated and that (b) there has been a change in moisture content between May 2006 and June 2007.

Evidence of desiccation is provided by the measured recovery between these dates and of change by the movement recorded every month.

It is possible, with varying degrees of confidence and success, to detect desiccation by all of the soil testing techniques at, or around, the same depth bGL. However, the amount of judgement required to arrive at an assessment, and the degree of confidence between and even within tests, varies enormously.

DISCUSSION (cont …)

The interpretation in this project has been assisted by viewing and comparing several sets of results over time. We also have the benefit here of precise levels and some understanding - gained over eighteen months – of what we are expecting to find.

Unless the results are clear and without ambiguity (more likely in cases of high suctions/strains with undisturbed samples) it could be difficult to make an assessment based solely on the outcome of one test - literally a 'snapshot in time' - without knowing the stress history and without precise levels.

With this caveat, the data allow a qualitative interpretation, but there does appear to be a significant quantitative (the magnitude of desiccation and the amount of swell resulting from its expiration) difference between them. Small 'blips' can result in allegations of root induced suctions. The tests are less reliable at low stresses for disturbed samples.

There are differences between measured ground movement (using precise levels) and laboratory estimates of swell derived from soils analysis and further work is being undertaken on this aspect. We have drawn some general conclusions from our research, and these are outlined below.

CONCLUSIONS

1. The range between estimates of swell using disturbed and undisturbed samples was less using the oedometer than the filter paper test. The bounding envelope between the upper and lower values of the oedometer results was smaller than for any of the other combinations and where there was variance, it was of a regular form.

2. Disturbed samples generally yielded the highest estimates of swell and the greatest scatter.

3. The filter paper method can produce a wide and apparently irregular profile. Some expertise and interpretation is required to assess where the Ko line should be. The line is sometimes wrong and this test does suffer from anomalies possibly related to salts, soil mineralogy and/or the filter papers. It can produce some misleading results that could lead to the estimate of swell being grossly over-estimated, or even suggesting there is desiccation when none exists.

4. Moisture Content determination may be useful as a supplementary tool and particularly when reviewing the results from the filter paper test. When there is an inference of an anomalous test result relating to the position of the Ko line when using the filter paper test a comparison with the moisture contents often clarifies whether the soil is desiccated or not. An increasing Ko line with a constant Mc suggest the results should be disregarded. See Appendix B.

CONCLUSIONS ***(cont …)***

5. The two interpretation techniques – that is, Driscoll's formula and the Liquidity Index - suffer from the problems associated with moisture contents generally. Desiccation can lead to small changes – often percentage points only – that are difficult to detect. None of the current techniques are definitive or even useful alone.

6. All of the tests perform better when the level of desiccation is high as we might expect. All become less clear and perhaps more confusing as the level of desiccation diminishes. Small differences at low levels of desiccation are sensitive to the smallest change using any of the soil testing techniques.

7. All tests confirm what the precise levels have recorded - that there has been (partial) rehydration with the ground rising and suctions dissipating as a result.

8. The root system of the Willow tree extended beyond its height and desiccation was recorded at the root periphery in all of the tests. BH 4 was 25mtrs from the tree trunk.

9. The depth of desiccation varies but is shown as peaking somewhere between 2 - 3mtrs bGL (see Appendix A), apart from areas where there may have been a moisture deficit extending through the winter of 2006, where it extends to ground level, and increases in magnitude.

10. Rehydration has taken place fairly quickly following the wetter weather - over one winter.

11. The estimates of swell on rehydration varied significantly and the output appeared unpredictable in the case of the filter paper test. Further work is needed on determining swell from laboratory results.

12. The qualitative interpretation of results at low suctions (less than 300 - 400kPa) requires considerable experience in some cases and could result in differences between engineers with regard to interpretation.

13. High suctions (greater than 500kPa) appear less prone to yielding anomalous results.

14. A great deal of experience is sometimes required to assess and distinguish not only between the various tests, but also when looking at different results from the same test. It is easy to understand why soil data provides such a fruitful area for disagreement between experts and litigious parties.

RECOMMENDATIONS

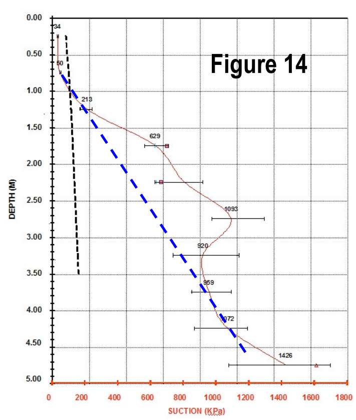
When using the oedometer test sample disturbance is possibly a secondary consideration. The profile of both disturbed and undisturbed samples is similar in amplitude. This test appears to deliver the most satisfactory results using either method of retrieval.

Disturbance can have an adverse effect on the filter paper test, which is also sensitive to the soil mineralogy at times.

We would advise that when using the filter paper test, bores are taken to a depth of 4.5 – 5mtrs bGL <u>and then</u> always align the Ko line with the values from the lower samples. Always have moistures for comparison. If they are around 30% and linear when the suction line increases linearly (even if that line has a blip) the results may be – are likely to be – anomalous.

Moistures alone deliver the least valuable results in our view, and the methods of interpreting them based on either Driscoll's formula or the Liquidity Index should be regarded as secondary measures to reinforce or discredit results from either of the above tests.

Whichever test is used, the analysis should be undertaken by someone with the required experience for reasons stated above. There are quite significant differences in profiles across the same test results.

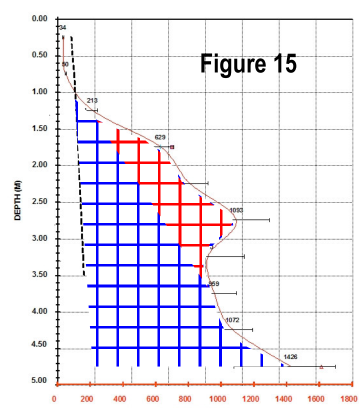


Left we have an example (BH 3, Test_2, Disturbed) of an anomalous filter paper test result with Ko plotted as a black dotted line. We would suggest the line should join the upper and lower values – see alternative (blue dotted line).

Only if the moisture content reduced at a point coincident with any bulge would we be 'confident' that this bulge is evidence of root induced desiccation.

The filter paper test will over-estimate swell if account isn't taken of the adjusted Ko line.

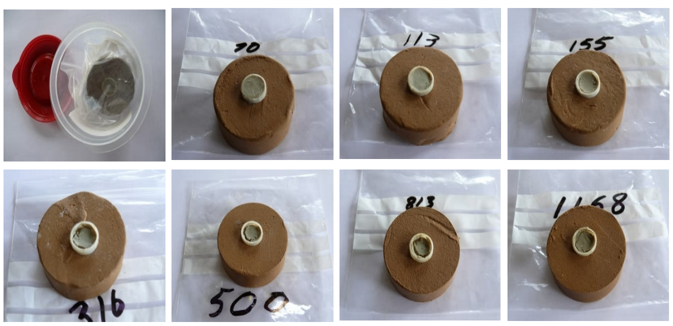
Right we see that the laboratory estimate (without adjustment) would include the blue and red shaded area. The actual estimate (assuming there is desiccation at all) might be the red shaded area only.

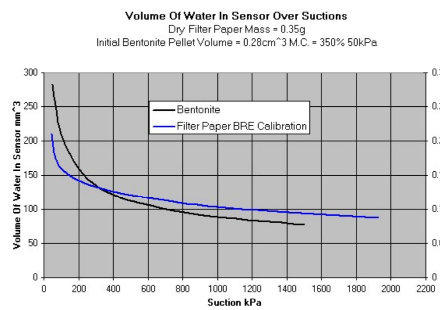


Next Steps

It is understood that Mike Crilly, Richard Driscoll and Tim Freeman are planning to re-visit the various techniques for assessing desiccation shortly. Richard Thomas and Tom Griffiths of RTG Expert Services have recently produced a review paper for CILA to assist their members understand the benefits and drawbacks of the various methods.

MatLab are working on the development of alternative tests and in particular exploring different methods for measuring suctions. Amongst these will be the use of a consolidated Bentonite clay pellet in place of the filter paper. On the face of it, this offers significant benefits and the test would still be relatively economic.





Initial results are encouraging and the calibration curve is reproduced above. This new technique is currently being researched and we will issue updates via the CRG Newsletter.

There is an aversion amongst the geotechnical community to even consider the use of the oedometer on disturbed samples but research over the last five years by MatLab suggests this can produce reliable results if the consolidation process is properly accounted for. Hopefully the work being undertaken by Mike Crilly, Richard Driscoll and Tim Freeman will explore this further.

The lateral drift we sometimes see whenn using the filter paper test may be related to the particular grade of paper used but the gradual increase in values with depth suggests the problem could lie in either (a) soil mineralogy or (b) the consolidation process and not taking account of the void ratio adequately. The bentonite pellet may resolve these issues.

END

Appendix

Appendix A

Zone of Tree Root Activity

Superimposing the results of the various tests onto one another to build a 'zone of root induced desiccation' envelope for the Willow produces the image below. It takes an irregular form no doubt defined by the soil mineralogy, rainfall, terrain and so forth.

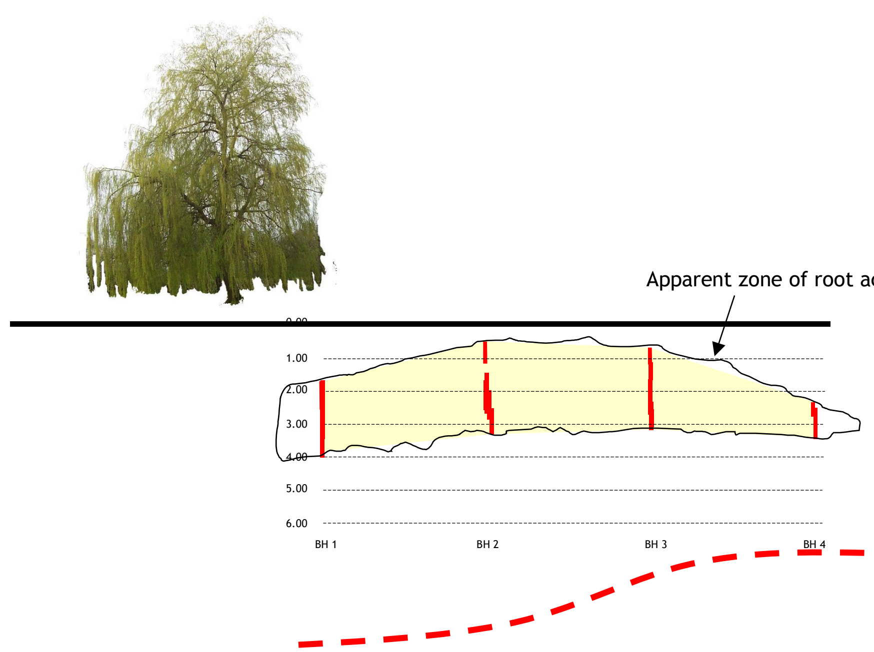


Figure 16
The apparent zone of moisture abstraction from the Willow showing the form and range.
The ground movement profile might still assume the profile of the red broken dotted line.

Appendix B

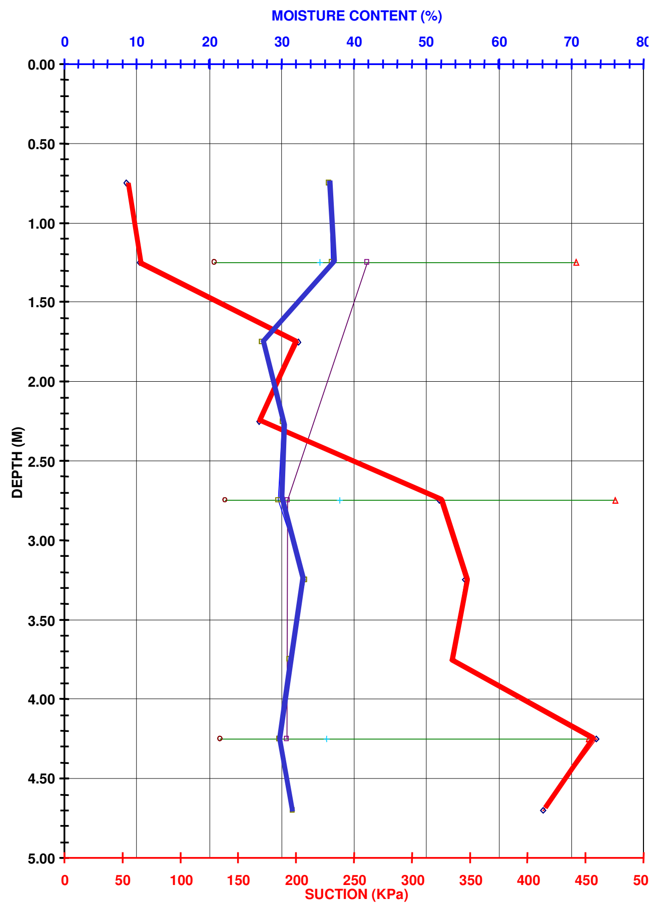


Figure 17
Illustration of an anomalous filter paper test result. Although the suctions increase linearly with depth, there is no associated reduction in the moisture content, which remains fairly constant at 30%.

A typical example (not taken from the Aldenham site) of an apparently anomalous result that is sometimes encountered when using the filter paper test. BH 3_Test 2 (Appendix A, Filter Paper results) is an example.

The suctions plot (red line) 'drifts' laterally with depth, but retains a fairly straight line exceeding the anticipated position of the Ko line. This profile is often associated with a fairly constant Mc at around 30%. Evidence of this anomaly is provided when the samples are re-tested using the oedometer and confirmed by previous research at Imperial College using the suction probe.

Appendix C

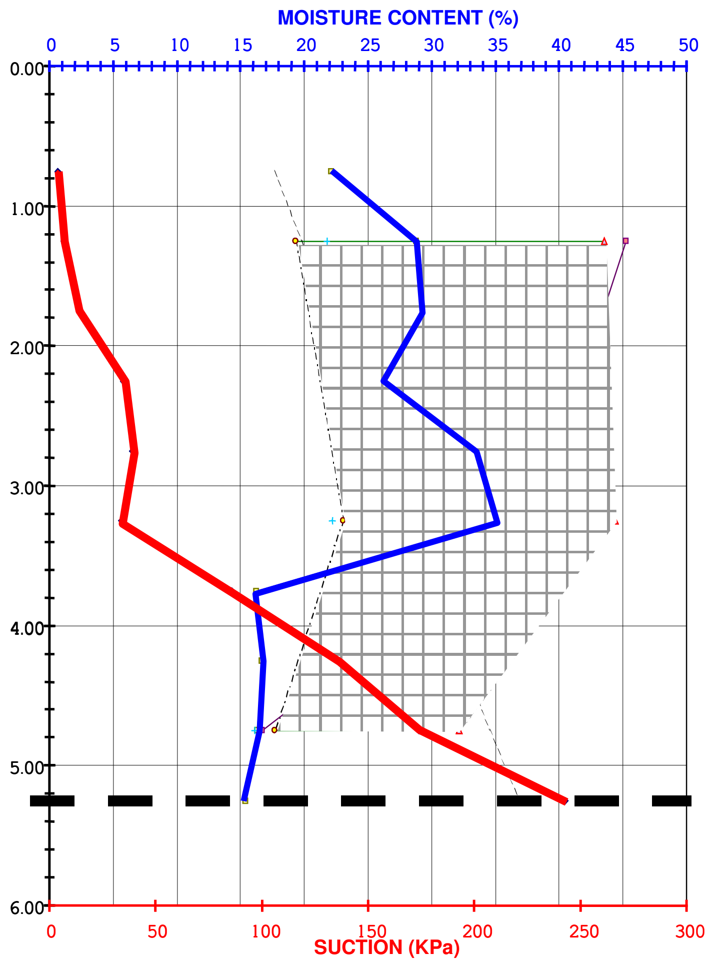


Figure 18
An example of under-draining, with both the suction and profile mirroring one-another. The laboratory description of the soil will often provide a clue, containing a reference to either chalk, sand or other free draining medium below the clay. The Plastic/Liquid Limit envelope is shaded in the above picture.

The difficulty with under-draining is the fact it can be confused with root induced suctions. It is important to look at the soil description from the lowest sample and the depth of the curve.

Obtaining samples deep enough to see the curve return to the Ko line resolves these problems.

Appendix D

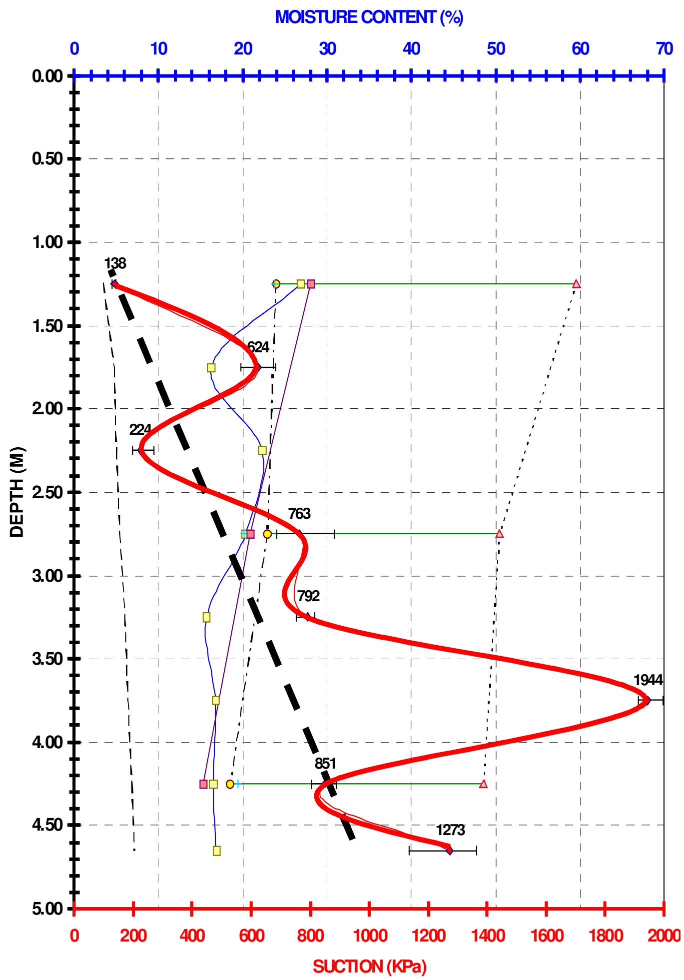


Figure 19

A profile often seen in the Weald Clay series or elsewhere in the presence of variable, stratified clay soils. A large bulge at depth (3.75trs mtrs bGL in this instance – not taken from Aldenham) can be indicative of heave where it is encountered following removal of trees for example. The Ko line as been adjusted significantly to take account of the anomalous results, but corroborative evidence is provided here by the moisture content profile. In addition, samples from all levels were tested using the oedometer, and the measured strains confirmed desiccation.