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Michael Long[1]

Use of a Downhole Block Sampler for Very Soft Organic Soils

ABSTRACT: Techniques required to successfully obtain downhole block samples of typical very soft high plasticity organic clay from Ireland are described. The vane shear strength of the material is as low as 4 kPa. These included using a sampler penetration rate three times faster than normally adopted. Comparisons are made between the results of laboratory tests on Sherbrooke block samples, on two fixed piston tube samplers and on a continuous sampler. In addition idealised tube sampling strains were imposed on block sample specimens prior to shearing (ISA approach). Both approaches confirmed that the material studied could not survive tube sampling undamaged, unlike the findings of a recent study in the Netherlands on Dutch organic soil. Tube sampling was found to have a more significant effect on triaxial test parameters that on those from the 1D compression testing, where the behaviour of the block sample specimens and those from one of the two tube samplers were similar to in situ response. Increasing levels of disturbance were associated with progressively more dilatant behaviour.

KEYWORDS: soft clays; silts; organic soil; sampling; disturbance; laboratory tests; in situ behaviour

[1] B.E., MEngSc, PhD, College Lecturer, Department of Civil Engineering, University College (UCD), Dublin, Earlsfort Terrace, Dublin 2, Ireland, Phone +353-1-7167333, Fax. +353-1-7167399, Mike.Long@ucd.ie

Introduction

There are many studies reported in the literature on sample disturbance effects on soft to firm inorganic clays. Some examples are the classic papers of La Rochelle and Lefebvre (1971) on Canadian Champlain clay, Lacasse et al. (1985) and Lunne et al. (1997a) on Norwegian clays, Hight et al. (1992) on Bothkennar clay from the UK and Tanaka et al. (1996) on Japanese clays. The findings from these studies suggest that in order to reliably obtain high quality samples downhole block samplers should be used. Recent work in The Netherlands (Den Haan 2003) has suggested that typical Dutch organic soil samples can survive undamaged, even if crude sampling techniques are used. It seems possible then that high plasticity organic clays, similar to those found extensively in alluvial and estuarine areas of the UK and Ireland, can survive tube sampling effects with only minimum damage. This of course has significant practical implications as relatively routine, and therefore cheaper, sampling techniques would be acceptable in such soils even for important projects.

Long and O'Riordan (2001) and Long (2002) have shown that even high quality piston sampling in very soft Irish organic soils can yield at best "good to fair" samples (after Lunne et al., 1997a). In order to obtain higher quality samples a downhole block sampling exercise, using the Sherbrooke block sampler, was undertaken in typical Irish soft organic clay (known as the "grey organic clay") at Athlone. As Sherbrooke block sampling had never previously been undertaken in soils as soft as those at Athlone, some modifications had to be made to the standard procedures. The objectives of this paper are to:

1. Describe the procedures used to successfully sample the very soft organic soils.
2. Demonstrate that the resulting downhole block samples were of high quality. This is achieved by comparing laboratory tests on specimens obtained from two fixed piston tube samplers and a continuous soil sampler with those from the block sampler. Laboratory

derived parameters are compared with the in situ behaviour of the material measured during embankment construction.

3. Assess whether typical Irish organic soil samples can survive tube sampling undamaged.

The Site

Athlone is located midway between Dublin and Galway in the Republic of Ireland. The Athlone Bypass, which passes to the north of the town, was constructed between 1982 and 1991. Part of the Bypass crosses an area underlain by up to 12 m of very soft clays on embankments up to 8.6 m high. Full details of the site and the ground conditions can be found in Long and O'Riordan (2001) and Long (2003). In the subsequent sections the field and laboratory techniques used will be described followed by a detailed site characterisation and analysis of the results.

Previous Experience with the Sherbrooke Block Sampler

For this project the sampler was hired from the Norwegian Geotechnical Institute (NGI), who had constructed the equipment under licence from the University of Sherbrooke where it was originally developed (Lefebvre and Poulin 1979). Sampling was carried out by the UK Building Research Establishment (BRE) under supervision by personnel from NGI. BRE had, at that time (Spring 1998), recently carried out a similar sampling exercise at the UK soft clay research site at Bothkennar. NGI has used the same block sampler on at least twelve sites in Norway. In addition NGI has collaborated with the Norwegian University of Science and Technology (NTNU) on a further two sites, with BRE on one site, with the Japanese Port and Harbour Research Authority (PHRI) on one site and with the University of Massachusetts, Amherst (UMASS) on five sites. A summary of NGI and UMass's experience of using the particular sampler is given on Table 1. Much of the original work in Canada, where the sampler was developed, was carried out on soils similar to the Gloucester clay listed on Table 1.

As will be shown below the material at the Athlone site falls on the upper bound of previous experience as far as moisture content and organic content is concerned and on the lower bound of clay content. None of the other materials have shear strength as low as those encountered at Athlone. A particular concern was that the relatively high silt content and the low shear strength of the material would mean that the sample would not be able to support itself temporarily during withdrawal of the block sampler from the boreholes and thus samples would not be recovered.

Sampling techniques used

Downhole Block Sampling

The Sherbrooke block sampler as described by Lefebvre and Poulin (1979), see Figure 1, uses three circumferential cutters combined with water pressure to core out an annulus around a block of soil to be sampled. The sampler has an outside diameter of 410 mm. Water exits through orifices located at the bottom ends of three hollow arms. With adequate water pressure and flow, a water jet is produced at the bottom of these arms that facilitates carving of the annulus and floating soil cuttings to the surface. Once the full length of the annulus is cored, three horizontal spring activated, bottom cutters are released to cut the bottom of the sample and provide basal support for retrieving it. The cutters are held in the open position (as in Figure 1) during carving of the annulus by torque springs and retaining pins. The pins are tripped from the surface using a drop weight. A full sample measures 250 mm diameter by 350 mm tall.

At Athlone samples were extracted from within a 450 mm diameter borehole. This borehole was advanced using a flat-bottomed auger in order to minimise disturbance effects at the base of the hole. A short length of temporary casing was used to stabilise the top part of the borehole. This allowed the water, which supported the borehole, to be maintained at a level above ground. This is similar to practice at NGI (Otter 1996), see Table 2. However workers at the University of Massachusetts, Amherst (DeGroot et al. 2003 and Landon and DeGroot 2006) use barite-bentonite drilling mud to stabilise the borehole.

The grey organic clay was first encountered at about 4.0 m and the first sampling was attempted from this depth to 4.35 m. Water pressure was set to between 200 and 250 kPa the same as that used by NGI (Otter 1996). The rate of sampler rotation was about 10 revolutions per minute, similar to that used at NGI and UMass (Table 2). Due to the softness and sensitivity of the material, a sampler penetration time of 3 minutes was chosen. This is much faster than the normal penetration time adopted by NGI and by UMass. Subsequently the sampler was rotated for about 2 minutes once the cutting knives were in place.

This sample was not recovered and it was felt that the failure was due to inadequate cleaning of the hole base, too high water pressure and too rapid rate of sampler penetration. For the next sample (4.5 m to 4.75 m), the hight was reduced to 250 mm, the water pressure was reduced to between 100 kPa and 200 kPa and the sampler penetration time was increased to 6 minutes. In this case sampling was successful. Subsequently five more samples of the grey organic clay were recovered before encountering the underlying brown laminated clay at 6.8 m. Some of these samples were the full 350 mm hight. It was also necessary to increase the water pressure to greater than 200 kPa as the jets occasionally became blocked.

Each sample was cleaned of surface material and sealed with a combination of cling film, tin foil and wax, immediately on recovery. They were then packed in wooden crates, surrounded by foam and transported to the UCD labs in Dublin by car.

Other Sampling Techniques

Sampling was also carried out using the 1 m long ELE 100 mm diameter fixed piston sampler. This is conventionally used in the UK and Ireland to obtain high quality samples of soft compressible material. It has an area ratio of 6.8% and no inside clearance. Recent studies (e.g. Hight 2001) have shown that a sharpened cutting edge can produce significantly better samples. Therefore samples were subsequently taken with a modified version of this sampler, in which the sample tube cutting edge was sharpened from the normal 30° to 5°. In both cases the hole was advanced using percussive means (conventional shell and auger drilling) within a fully lined 200 mm diameter borehole. Possible disturbance at the base of the borehole was an obvious concern and the borehole was maintained full of water to above ground level in order to minimise these effects.

Continuous soil samples of 65 mm in diameter, were obtained using a MOSTAP® soil sampler (Long 2002). It has a cutting edge angle of 15° and an area ratio of about 105%. A thin walled (2 mm) sampling tube (or liner) acts as a guide for a piston during sampling and distributes the stocking uniformly around the sample. The purpose of the stocking is to minimise friction. Together with the liner it serves to effectively transport and store the sample. For this technique no borehole is required. No difficulties were encountered holding the stocking fixed.

Boreholes for the 30° piston tube, Sherbrooke block and MOSTAP® specimens were all drilled within a few meters of one another as shown on Figure 2 (Location called Profile D by Long and O'Riordan 2001). The 5° piston tube borehole was drilled at Profile C, some 110 m west of Profile D. Field vanes tests were carried out for the original relief road investigation.

Laboratory Testing

The principal means of studying the difference in shearing behaviour of the material from the block and tube samples was by means of anisotropically consolidated undrained triaxial tests (CAUC). In addition some incremental load oedometer tests (IL) were performed to study any sampling induced effects on compressibility parameters.

Triaxial Tests

The procedures used were broadly those adopted as standard by the Norwegian Geotechnical Institute (NGI) as describe by Berre (1981). The specimen, of diameter as extruded for the piston samples or trimmed to 100 mm and 50 mm for the block and MOSTAP® specimens respectively, was cut to a diameter height ratio of about 1.8. A cell pressure of $0.5\sigma_{v0}$ (total in situ vertical stress) was applied and the initial effective stress or suction (u_r) was measured. Initially some isotropic consolidation was carried out at an effective cell pressure of 0.6 σ'_{h0} before slowly applying the in situ stress. K_0 was assumed to equal 0.6, based on correlation with plasticity index (I_p) from Brooker and Ireland (1965) and Berre (1982). The final consolidation stresses are kept constant until the rate of volumetric strain is less than 0.0001% per minute. Shearing was carried out at the slow rate of 4.5% per day so as to ensure equal distribution pore pressure throughout these relatively large specimens (Smith et al. 1992). Axial strains were measured locally using Hall effect gauges.

Oedometer Tests

These comprised conventional 24 hour incremental load (IL) tests with initial load increments to $0.25\sigma'_{v0}$ (the in situ vertical effective stress), $0.5\sigma'_{v0}$, $0.75\sigma'_{v0}$, and $1.0\sigma'_{v0}$. Otherwise the procedures used were again broadly those adopted as standard by NGI (Sandbækken et al. 1986). Piston tube specimens were extruded directly into 100 mm diameter oedometer rings so as to minimise contact with soil and reduce disturbance. Block and MOSTAP® specimens were trimmed to slightly greater than 100 mm and 50 mm diameter respectively prior to slowly pushing in a lubricated oedometer ring.

Site Characterisation

Geology and Ground Conditions

A summary of the available field and laboratory information for the Athlone site, noting those data which are pertinent to this study, is given on Table 3. The soft soils at Athlone are glacial lake deposits, which were laid down during the retreat of the glaciers at the end of the last ice age some 10,000 to 20,000 years B.P. Two distinct strata were formed, as can be seen on Figure 3. The lower soils are very soft brown horizontally laminated (varved) clays and silts with clearly visible partings typically 1 mm to 2 mm thick. As the climate became warmer, the depositional environment changed and the upper soils show only some signs of varving and have an increasing organic content. The material deposited under these conditions is homogenous grey organic clay and silt and is the subject of this paper. It was chosen for study because soil of this type is widespread throughout Ireland. Thin layers of calcareous marl and peat overlie these glacial lake bed clays. The water table is located close to ground level.

In addition to the standard CPTU tests some T-bar tests were also carried out as shown on Figure 3. These tests involved replacing the cone tip by a roughened T-bar of diameter 40 mm and length 250 mm, thus having an area ten times that of the standard cone (Long and Gudjonsson 2004). All of the tests were located within a few metres of one another and about 25 m north west of the location of the Sherbrooke block sampling, see Figure 2. There is a reasonable agreement between the two CPTU tests and the two T-bar tests. CPTU q_{net} values are very low and increase from about 0.15 MPa to 0.35 MPa in the grey organic clay, then reduce to about 0.2 MPa in the brown laminated clay. Excess pore pressure (u_2) values for both tests are practically identical and show a relatively uniform increase with depth, until about 10.5 m, below which there is a greater rate of increase. T-bar net resistance values are also very low. In the grey organic clay they show a slight increase with depth from about 0.1 MPa to 0.25 MPa and these values are similar to those measured using the CPTU.

Classification of soil

In engineering terms the grey organic clay can be described as a very soft to soft dark grey slightly sandy organic clay / silt with occasional shell fragments. The organic fraction is sometimes visible in distinct pockets comprising decayed plant remains and rootlets, as shown on Figure 4a. A scanning electron microscope image of the material is shown on Figure 4b. Organic content in the form of plant and animal debris (freshwater diatoms) interweaving with inorganic particles are clearly evident.

Organic content tests show highly variable results (Figure 5). Loss on ignition (LOI) values vary between 3.5% and 9.2% with an average of about 5.6%. According to the Unified Soil Classification System (USCS) the soil is classified as “organic” if its liquid limit (w_L) on oven drying is less than 75% of the value before drying. Atterberg limit tests on oven-dried specimens of the material are compared to those on soil in its natural state on Figure 6 (All tests from Profile C). On average the oven dried samples have w_L of 63% of those on the natural soil. Thus the soil can be classified as “organic”. Though the LOI values are relatively low for an “organic” material, the term is considered appropriate as this fraction has such a significant effect on the material behaviour, as will be shown below.

Index Properties

Index properties, from the various sample types, are shown on Figure 5. Data from the original relief road site investigation (1m long, 100 mm diameter ELE tubes with a 30° cutting edge) are also included. As is characteristic for natural organic clay, there is significant scatter in the data. The general trend is for a decrease in moisture content (w) from about 120% at the top of the stratum to about 40% at its base, with a corresponding increase in bulk density (ρ_b) from about 1.4 Mg/m^3 to 1.6 Mg/m^3. There is no apparent difference between the data from the different samplers or the two investigations. Average clay and silt content are relatively constant at about 26% and 66% respectively. Fine sand makes up the remainder of the material and the particle size distribution is uniform. Liquid limit (w_L) and plasticity index (I_p) values are variable being generally greater than 60% and 30% respectively but generally straddle the “A” line on a standard plasticity chart. Thus the material is classified as a clay / silt of “high plasticity”. Values of w_L are often close to the natural water content and the average value of the liquidity index is about 1.0.

Undrained Strength and Sensitivity

Vane strength data at the location of the block sampling and CPTU testing are plotted on Figure 7. Data were obtained from a 150 mm by 75 mm Farnell field vane (tests carried out during shell and auger drilling) with a rate of rotation between 5º / min. and 9º / min and only a short delay between insertion and testing. Undrained shear strength (s_u) decreases with depth in the stratum from 15 kPa to 20 kPa to about 5 kPa at the interface with the brown laminated clay. It is likely that the higher values are associated with shearing of organic fibres. A line representing the typical strength of $0.3\sigma'_{v0}$ for normally consolidated clay is also shown and it can be seen that above 5 m the material appears to be lightly overconsolidated, probably due to the effects of seasonally varying groundwater. At about 5 m, the vane strengths fall on or close to the $0.3\sigma'_{v0}$ line. As would be expected CAUC triaxial strength values for the block samples are two to three times the vane s_u values.

Field vane sensitivity decrease from about 10 at the top of the stratum to 2 with depth. T-bar cyclic tests yield similar results. According to Smith (1982) the soil is then classified as “medium sensitive” to “sensitive”. It is likely that the sensitivity is a result of leaching by organic dispersing agents from the overlying peat and calcareous marl (Söderblom 1966).

Conclusions on Natural Material Variability

Despite the natural material variability due to its organic nature, data from the CPTU and T-bar tests (Figure 1) suggest that, on a macroscopic scale, the material is relatively uniform over the depth range of the sampling comparison exercise (2.6 m to 7 m). In order to reduce as far as possible the effects of variability, the largest size specimens possible, i.e. 100 mm by 180 mm in the case of the triaxial tests were used in the study.

Analysis of Triaxial Test Results

Normalised Volume and Void Ratio Change During Consolidation

The results of the thirteen CAUC triaxial tests are summarised on Table 4. Much recent research into sample quality has made use of either the normalised volume change ($\varepsilon_{v0} = \Delta V/V_0$) or the normalised void ratio change ($\Delta e/e_0$) required to reconsolidate the sample anisotropically to the in situ effective stress (σ'_{h0}, σ'_{v0}) to assess sample quality. Measured values can then be compared to published criteria such as those of Kleven et al. (1986) or Lunne et al. (1997a), as shown on Figure 8. This technique and the corresponding criteria was developed for uniform marine clays and its application to organic clays therefore needs to be treated with caution.

According to the Kleven et al. (1986) criterion more or less all of the specimens would be categorised as “very poor”. However Lunne et al.’s (1997a) revised criterion ($\Delta e/e_0$) is a measure of the change in pore volume to the initial pore volume, whereas ε_{v0} is equal to the change in pore volume divided by the initial total volume. They based their argument on the assumption that a certain change in pore volume will be increasingly detrimental to the particle skeleton as the initial pore volume decreases. A reclassification of the data according to Lunne et al. (1997a) then suggests that the specimens are either “very good to excellent” or “good to fair”. On average the block samples show the highest quality, with all of the other sampler types showing similar values.

Undrained Stress - Strain Behaviour and Shear Strength

Normalised deviator stress (σ'_a-σ'_r) / strain plots for all the triaxial tests are shown on Figure 9. The data have been normalised by the in-situ mean effective stress $s'_0 = (\sigma'_{h0}+\sigma'_{v0})/2$. It can be observed that there is some difference in behaviour between the tube samples and the block samples. The four block sample test results are very consistent. They exhibit ductile behaviour, as would be expected for an organic clay, with average s_u/σ'_{v0} of about 0.79 and strain at peak (ε_f) of 6.7% on average. It can be seen that the stress / strain response for the 30° and 5° specimens are less consistent than for the block samples and have average s_u/σ'_{v0} of 0.51 and 0.41 respectively. As has been reported by others sampling disturbance typically reduces s_u. If has also be found that disturbance increases ε_f. However no such clear pattern was observed here and the 30° and 5° specimens have similar average values to the block samples of 5.7% and 3.9% respectively. The MOSTAP® test results show clear evidence of disturbance with large strains being required to develop peak strength.

These relatively high values of s_u/σ'_{v0} are consistent with the degree of overconsolidation of the material as can be seen from the CPTU plots on Figure 3. Lunne et al. (1997b) suggested that a normally consolidated clay has net cone resistance (q_{net}) of $2.5\sigma'_{v0}$ to $5\sigma'_{v0}$. Here q_{net}/σ'_{v0} is between 7.5 and 10, consistent with an overconsolidation ratio (OCR) of 2 to 3. The likely cause of overconsolidation is the seasonally fluctuating water table. Somewhat lower values were obtained from the (more disturbed) oedometer tests, which will be discussed below. Wood (1994) suggested:

$$\frac{s_u/\sigma_{v0}^{`}}{(s_u/\sigma_{v0}^{`})_{nc}} = OCR^{0.8} \qquad (1)$$

where: nc refers to the normally consolidated state and $(s_u/\sigma'_{v0})_{nc}$ for CAUC tests is typically 0.3. Thus here for OCR of 2 to 3, s_u/σ'_{v0}, should be in the range 0.52 to 0.72, which is in agreement with the block sample test results.

Undrained Stress Paths

The corresponding normalised stress path plots are shown on Figure 10. Lunne et al. (1997a) suggested that the early part of the conventional (s', t') stress path plot is dramatically influenced by sample disturbance. According to these authors for a “perfect” specimen, pre-peak, in which there is minimum slippage between the particles, the initial stress path (plotted in s', t' space as here) slope will be 1 horizontal to 3 vertical. An undisturbed specimen will retain this more or less linear stress path until the failure line is reached. From Figure 10 it can be seen that the block sample behaviour is closest to this ideal.

Lunne et al. (1997a) proposed a technique for quantifying this is by means of the pore pressure dilatancy parameter (D), where:

$$D = \frac{1}{2}\left[\frac{\Delta s^{`}}{\Delta t^{`}} - \frac{1}{3}\right] \qquad (2)$$

and:

$\Delta s'$ = change in mean effective stress,

$\Delta t'$ = change in shear stress.

They suggested determining D at 2/3 of the peak shear stress less the initial stress and showed that D = 0 (zero dilatancy) corresponds to a line with an inclination of 1 horizontal to 3 vertical. Data for the Athlone grey organic, summarised on Table 4, confirm that average D for the block samples is closest to zero.

Post peak all of the tests show contractive behaviour up to critical state conditions and this behaviour is typical of normally to lightly oveconsolidated clay. The MOSTAP® test results are more erratic. A line representing a Mohr-Coulomb strength of $\phi' = 40^{o}$ and $c' \approx 5$ kPa has also been plotted on Figure 10. These high ϕ' values are due to the effect of the organic fibres as described above. Similar high values are reported for Dutch organic clays (Den Hann 2003). Stress paths for all four block sample tests ultimately fall on this line. In general all other tests show stress paths which lie below this line. It is possible that the tube and MOSTAP® sampling has led to some destructuration of the soil and has in effect destroyed the c' component, possibly by damaging the additional reinforcement provided by the organic material.

Other Parameters Measured in CAUC Triaxial Tests

Values Skempton’s pore pressure coefficient A_f at peak and normalised secant stiffness values (E_{sec}) at 0.01% strain, for each sampler type are also summarised on Table 4. Although it seems that tube sampling, particularly that of the 30° specimens, results in increased A_f compared to the block samples, the scatter in the remainder of the data masks any trends.

Behaviour of Block Samples Subjected to “Tube Sampling” Strains

Background

It is possible that the behaviour described in the section above arrises simply from natural material variability and not from sample disturbance. In order to investigate these effects further, block sample specimens were subjected to strain paths, which mimicked the theoretical tube sampling strains, prior to shearing the samples. If the same pattern of behaviour as discussed above is reproduced, for increasing levels of disturbance, then it could be concluded that natural material variability is not the explanation for the discovered behaviour. Santagata and Germaine (2002) call this technique the "ideal sampling approach" (ISA) and used it to study the effects of tube sampling on the undrained behaviour of resedimented Boston blue clay.

Theoretical work at the University of Surrey (Clayton and Siddique 1999) showed that the strain induced during tube sampling is very sensitive to the sampler geometry, in particular the cutting edge angle. For conventional ELE type piston tube samplers, with no inside clearance, there are no extension strains induced as the sample enters and moves up inside the tube. Maximum compression strains were estimated to be about 0.6% for tubes with a sharpened 5° edge and more than 1% for the more usual tube with a 30° edge.

Tests to mimic samplers used in this study

In this study the ISA was used to study the effects of tube sampling by initially imposing compressive axial strains (of 0.8%, 1.3% and 3.05% as measured using local transducers) on block sample specimens, and then subsequently reconsolidating (using same approach as for CAUC tests) and shearing them to failure. Details of the tests together with some results are given on Table 5. A typical result from the earlier study (100g10 – block sample at 5.4 m) is also given on the Table for comparison.

Deviator stress / strain and stress path plots for the final shearing are shown on Figure 11. In tests bg1 and bg3 the tube sampling strains were 0.8% and 1.3% respectively and thus most representative of the samplers used in this study. For these tests the peak strength is lower than that for the undisturbed block sample. The stress path plots show an increasing level of pre-peak contraction and divergence from the idealised behaviour proposed by Lunne et al. 1997a). Similarly values of A_f increase (Table 5). This pattern of behaviour is the same as that noted when the block and tube samples were compared above.

Based on the consistency of these findings from comparing the block and tube samples and from the ISA approach, it may be concluded then that the difference in results between the two sets of samples is not mainly due to natural material variability but due to the effect of undrained tube sample strains.

Test with high imposed strain

In test bg4 the imposed strain was 3.05% and thus greater than that theoretically associated with the samplers used in this study. Here two overlapping effects occur, those of the imposed strains and of reconsolidation. The net result is a more dilative response with peak strength occurring at large strain. This is similar to observations made by Santagata and Germaine (2002) for their work on resedimented Boston blue clay, where they found that increasing levels of disturbance are associated with a more dilative response.

Analysis of Oedometer Test Results

Stress - Strain Behaviour

The results of sixteen IL oedometer tests, i.e. four on each sampler type, are summarised on Table 6. Typical log σ'_{v0} – strain and stress - constrained modulus (M) plots for each of the sampler types are shown on Figure 12. All samples, except for the MOSTAP® are from depth 5.5 m. The block sample and 30° tube tests show a similar response and are of the characteristic rounded shape for an organic material material. For both tests definition of yield (or preconsolidation stress, p'_c) by the Casagrande (1936) technique is relatively unambiguous. In contrast both the 5° and MOSTAP® tests show a much flatter curve, i.e. a stiffer response and it is more difficult to define p'_c. It is recognised that as oedometer tests are on thin specimens, then variations in material type will strongly affect the results. In particular silty soils will give flatter curves.

Similarly the plots of constrained modulus, M, against stress confirm the stiffer response of the 5° and MOSTAP® specimens. It is also possible to estimate p'_c from these curves, using the Janbu (1963) for the block and 30° specimens (approximately point of minimum M before final straight line portion in the virgin consolidation range) but impossible for the 5° and MOSTAP® specimens.

Normalised Void Ratio Change to Initial Vertical Effective Stress

As for the triaxial tests the $\Delta V/V_0$ and $\Delta e/e_0$ (i.e. normalised volume and void ratio changes to σ'_{v0}) were studied in an attempt to assess sample quality (Table 6). The data are very scattered. However on the block and 30° specimens have the lowest average values (≈6% and ≈0.08), which categorised these specimens as “poor”. The MOSTAP® specimens fall in the “very poor” category with the 5° tube specimens in between. These values are higher than those for the triaxial specimens. Similar findings have been reported by others. It seems that the insertion of the oedometer ring into the specimen results in some additional damage.

Parameters Derived from IL Tests

Values of OCR (using both the Janbu and Casagrande approaches), normalised M_0 (i.e. M at σ'_{v0}) and modulus number m (δM / $\delta\sigma'$) in the virgin consolidation zone are summarised on Table 6. As has been found by previous researchers, OCR from the Janbu (1963) approach is slightly greater than that from Casagrande (1936), by perhaps 5% in this case. The tests confirm that the material is lightly overconsolidated with OCR values lower than those derived from the triaxial tests. It is well known that sampling disturbance causes a reduction in OCR and has been discussed above the oedometer specimens were more disturbed than the triaxial ones.

As has been previously discussed above, the block and 30° tube specimens give the lowest values of m, i.e. more compressible. There is some other evidence in the literature that sampling disturbance increases post-yield stiffness (Karlsrud 1995; Hight et al. 1992). All specimens give similar values of M_0 / σ'_{v0}.

Comparison with In Situ Behaviour

Of perhaps more interest is to compare the block and 30° tube sample tests with some field compressibility data as shown on Figure 13 (data from Long and O'Riordan 2001). These data were obtained in the field during the construction of two trial embankments (known as the main and subsidiary trails) and from instrumented cross sections of the main works embankments (at Profiles C, D, E and F as described above).

Magnet extensometers were placed at the top, middle and bottom of the organic clay stratum so therefore field strains were directly obtained. Vertical effective stress was calculated from total stress less pore pressure from piezometers installed in the centre of the organic clay layer. Stress – strain curves can then be constructed to compare with oedometer test results, as shown on Figure 13.

It is only possible to easily determine the in situ p'_c value for Main Works Profile F, where instruments in the organic clay were at a higher elevation than for the other sections. The in situ data suggests p'_c is approximately 60 kPa giving an OCR of about 3.0 (consistent with the triaxial test results as discussed above).

In the normally consolidated zone, all the field data show similar behaviour and in general indicate a more compressible response than that of the block and 30° specimens (which in turn were more compressible than the MOSTAP® and 5° specimens). However inspection of the M – stress plots indicate that the resulting difference in the stiffness values between the field and the laboratory data are small. It is very likely that rate of loading effects contribute to the lower stiffness values measured in the field. Field loading is slower and therefore a more flexible response will result.

Conclusions

1. The modifications to standard techniques required to obtain downhole block samples of typical Irish soft high plasticity organic clays have been described.
2. This work confirms that these soils cannot survive tube sampling undamaged. Tube sampling was found to decrease normalised triaxial strength and to increase the pore pressure parameter, A_f, The same result was found both by comparing specimens from different samplers and in a study where idealised tube sampling strains were imposed on block sample specimens (ISA approach).
3. In both studies it was found that increasing levels of disturbance were associated with progressively more dilatant behaviour.

4. Tube sampling also had an effect on 1D compression behaviour but both the Sherbrooke block samples and one of the two types of piston tube sample showed similar response to that measured in situ beneath highway embankments.
5. The higher quality of the Sherbrooke block samples was most evident in the volume strains required to reconsolidate specimens to in situ stress ($\Delta e/e_0$) and in the shape and consistency of the stress / strain and stress path plots.

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LIST OF FIGURES

Fig. No.	Caption	File Name*
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3	CPTU and T-bar test results	DELL+D(D)/Papers/ASTMGrey/Athcptu.xls+grf
4	Organic content in clay (a) macroscopic, (b) microscopic	Dell+D(D)/Papers/ASTMGrey/visibleorganics.jpg/semgreyclay.jpg
5	Index properties	DELL+D(D)/Papers/ASTMGrey/Athbasics.xls+Greybasics.grf
6	Influence of oven drying on Atterberg limits	Dell+D(D)/Papers/ASTMGrey/PlasticitySectionC.grf
7	Undrained shear strength and sensitivity	DELL+D(D)/Papers/ASTMGrey/Athsu.xls+Greysu.grf
8	Assessment of sample quality – triaxial tests	DELL+D(D)/ASTMGrey/Delee0triax.grf+.Delee0.xls
9	CAUC test - deviator stress – strain curves	DELL+D(D)/ASTMGrey/Triax.xls+Devstress.grf
10	CAUC test – stress path plots	DELL+D(D)/ASTMGrey/Triax.xls+Stresspath.grf
11	Results of ISA tests on block samples	DELL+D(D)/ASTMGrey/Balighgrey.xls+.grf
12	IL oedometer test results	DELL+D(D)/ASTMGrey/Oedallsamplers.grf+oedcomp.xls
13	In-situ compressbility	DELL+D(D)/ASTMgrey/oedcomp.grf+.xls

* Microsoft EXCEL® and Golden Software GRAPHER® used throughout.

TABLE 1 - Summary of previous experience with Sherbrooke block sampler

Site	w (%)	w_L (%)	I_p (%)	Clay con. (%)	Org. con. (%)	s_u vane (kPa)	S_t	Reference
NGI								
Emmerstad	40-48	24-32	3-12	40	-	15-20	60-∞	Lacasse et al. (1985)
Ellingsrud	34-40	25-29	5-8	37	-	8	60-∞	As above
Onsøy	58-70	56-74	30-44	60	0.6	15-30	6-9	As above. Lunne et al. (2003)
Drammen	32-39	-	11-16	-	-	12-24	4-10	Berre (1987)
Eidsvoll	25-33	31-42	13-19	37-48	-	≈40	2-5	Karlsrud et al. (1995, 1996)
Leirsund	30-39	30-40	9-18	36-49	-	≈80	5-20	As above
Lierstranda	30-40	35	15	36-44	<0.3	20-60	8-12	Lunne et al. (1997a)
Nykirke	25-32	19-30	5-9	21-55	1.25	≈40	77-∞	Hermann and Jensen (2000)
Leira	30-34	-	12-14	36-49	-	-	7-10	Karlsrud et al. (2005)
Hvalsdalen	31-39	-	9-17	40-49	-	-	5-240	As above
Buvika	29-33	-	6-13	28-33	-	-	10-160	As above
Nybakk	32-39	25-45	8-18	33-46	-	15-40	7-135	As above
NGI/NTNU								
Kvenild	25-40	24-36	4-22	3-47	0	25-30	50-70	Ørbech (1999)
Glava	30-40	30-42	15-30	30-61	0	25-50	5-10	Sandven and Sjursen (1996)
NGI/BRE								
Bothkennar	40-75	60-80	30-50	17-35	3-5	20-60	8-13	Karlsrud et al. (1996), Lunne et al. (1997a)
NGI/PHRI								
Ariake	107	100	50	58	-	14-41	-	Oka et al. (1996)
UMASS								
Amherst	46-59	35-60	10-25	40-65	0.5	25-40	10	DeGroot et al. (2003)
Boston	40-52	45	20	-	-	20-75	5-21	As above.
	38-59	45-50	18-20	55-65	-	-	20-30	Landon & DeGroot (2006)

Gloucester	56-90	≈26	25	50-70	-	>25	5-90	As above
Atchafalaya	50-90	-	85	-	-	-	1.2	As above
Burswood	55-90	60-75	35-40	-	-	20-25	2-5	Landon & DeGroot (2006)
This study								
Athlone	40-95	>60	>30	≈26	≈5	5-15	2-10	This paper

Table 2 – Summary of drilling and sampling parameters

Operator	BH diameter (mm)	Stabilisation	Water pressure (kPa)	Rotation rate (revs. /min.)	Pen. rate (mm/min.)	Reference
NGI	430	Water	200 - 250	5	14 - 23	Otter 1996
UMass	430	Mud	-	5 - 15	17 - 30	DeGroot et al. 2003 Landon & DeGroot 2006
This study	450	Water	100 - 250	10	40 - 55	

Table 3 – Summary of available data for Athlone site

Field data	Presented here	Lab data	Presented here
Field vane in borehole	✓	Lab vane	X
Hand vane on samples	X	Index testing	✓
CPTU	✓	IL oedometer tests	✓
T-bar	✓	Triaxial tests	
		CAUC, CAUE, UU	✓, X, X
Cone pressuremeter	X	ISA triaxial tests	✓
In situ compression measurements	✓		

TABLE 4 - Summary of CAUC triaxial tests

Test number	Depth (m)	w (%)	ρ_b (Mg/m^3)	$\Delta V/V_0$* (%)	ε_f † (%)	E_{sec} (ε =0.01%) (MPa)	D**	s_u/σ'_{v0}	A_f†
Block									
100g7	4.95	104	1.442	4.1	7.2	61	-0.17	0.84	0.55
100g8	4.95	110	1.430	2.7	6.2	49	-0.02	0.75	0.5
100g10	5.4	95	1.488	4.4	6.3	50	-0.17	0.79	0.5
100g12	5.75	84	1.595	7.3	7.2	48	-0.16	0.77	0.55
30° tube									
50g1	3.6	60	1.589	5.5	5.4	45	-0.51	0.47	0.62
50g8	5.6	50	1.754	4.5	1.1	17	-0.05	0.35	1.25
100g6	5.3	73	1.564	4.8	4.5	110	-0.27	0.51	1.00
100g11	3.2	51	1.707	5.4	11.6	40	-0.2	0.70	1.00
5° tube									
50g4	6.6	36	1.828	4.5	1.9	28	0.33	0.35	0.88
100g4	5.3	41	1.800	2.8	3.8	130	-0.03	0.43	0.89
100g5	7.0	39	1.877	8.0	6.0	130	0.05	0.46	0.35
MOSTAP®									
50g5	5.8	96	1.456	6.8	8.3	75	-0.33	0.59	0.67
50g6	2.6	87	1.453	9.1	11.7	55	-0.12	0.33	0.46

* normalised volume change during consolidation, ** pore pressure dilatancy parameter

†f refers to peak deviator stress

TABLE 5 - Ideal sampling approach (ISA) CAUC tests

Test number	Initial strain (%)	Depth (m)	w (%)	ρ_b (Mg/m^3)	ε_f (%)	E_{sec} (ε =0.01%) (MPa)	D	s_u/σ'_{v0}	A_f[†]
100g10	0	5.4	95	1.488	6.3	50	-0.17	0.79	0.5
bg1	0.8	5.75	83	1.658	5.0	90	-0.04	0.58	0.57
bg3	1.3	4.6	57	1.642	4.7	60	-0.53	0.52	0.81
bg4	3.05	4.6	57	1.717	8.5	43	-0.06	0.83	0.42

* for notation, see Table 2

TABLE 6 - Summary of IL oedometer tests

Test number	Depth (m)	w (%)	ρ_b (Mg/m^3)	$\Delta V/V_0$[*] (%)	$\Delta e/e_0$[*]	OCR[†] (kPa) Casa	OCR[†] (kPa) Janbu	M_0 (kPa)	m
Block									
G17	4.9	95	1.549	6.7	0.101	n/a	n/a	400	7.3
G18	5.5	88	1.526	6.6	0.099	1.1	1.2	800	7.3
G19	5.4	88	1.465	3.9	0.059	n/a	n/a	500	9
G20	5.5	88	1.477	8.6	0.105	0.9	1.0	400	4.4
30° tube									
G5	3.9	78	1.510	4.3	0.067	1.1	1.2	850	8
G6	4.8	53	1.720	5.9	0.116	1.0	n/a	650	8.6
G8	5.5	57	1.589	3.6	0.063	0.9	0.9	900	8
G9	5.5	64	1.581	7.0	0.116	n/a	n/a	900	8.3
5° tube									

G10	3.1	77	1.559	10.7	0.166	n/a	n/a	800	12
G11	5.8	33	1.987	6.7	0.114	0.8	0.9	600	20
G12	5.6	37	1.913	7.3	0.200	n/a	0.9	1200	11.3
G15	5.5	37	1.906	4.0	0.093	1.3	1.2	1300	11.3
MOSTAP®									
G24	5.2	47	1.745	7.4	0.120	n/a	n/a	450	14.7
G25	4.8	46	1.777	11.9	0.200	n/a	n/a	1200	10.6
G26	5.9	55	1.680	12.0	0.200	n/a	n/a	500	17.9
G27	3.6	75	1.540	12.0	0.200	n/a	n/a	800	11.4

* normalised volume or void ratio change during consolidation

† OCR from preconsolidation pressure (p'_c) / σ'_{v0} after Casagrande (1936) or Janbu (1963). OCR should always exceed 1. Values less than 1 reported here to indicate level of disturbance.

ASTM – Geotechnical Testing Journal (GTJ)

Use of a Downhole Block Sampler for Very Soft Organic Soils - Michael Long

FIGURES

Figure 1. Sherbrooke block sampler in operation at Athlone site

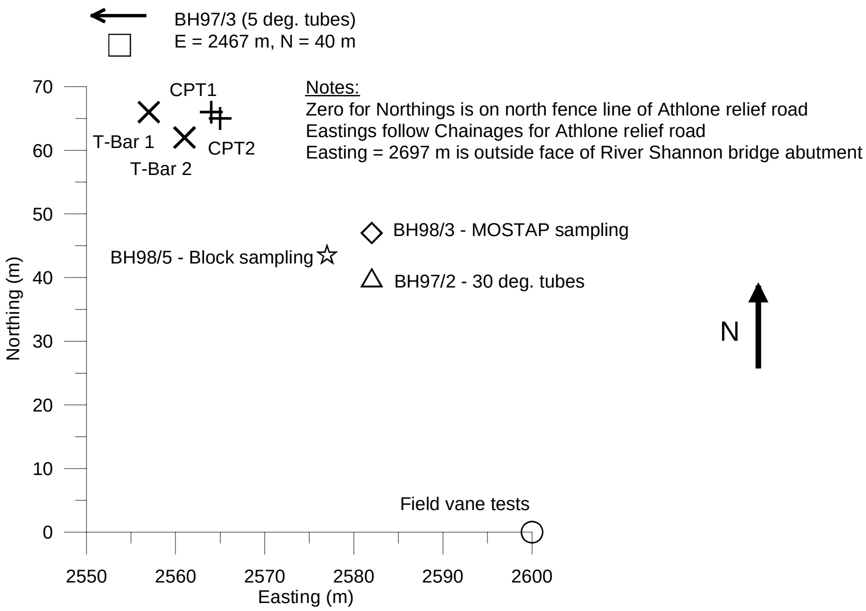

Figure 2. Location of boreholes and field tests

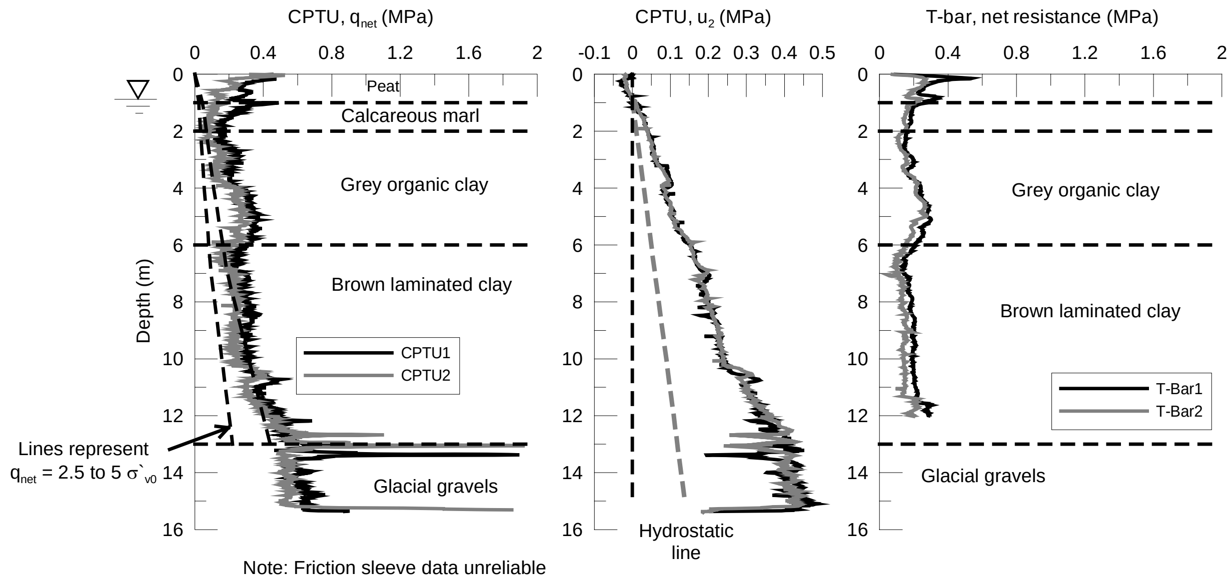

Figure 3. CPTU and T-bar test results

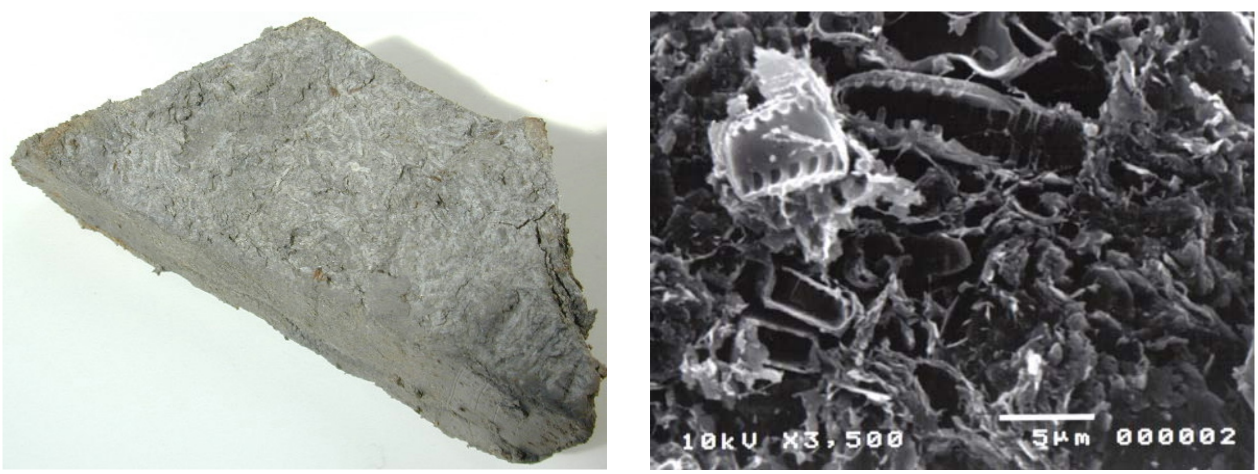

Figure 4. Organic content in clay (5 m depth) (a) visible macroscopic and (b) microscopic

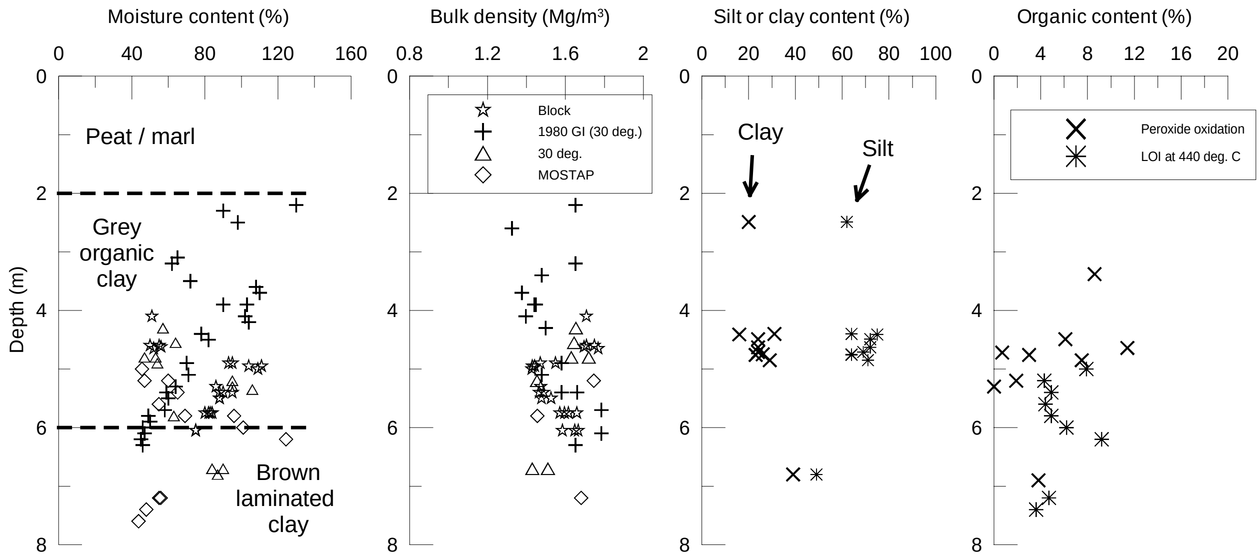

Figure 5. Index properties

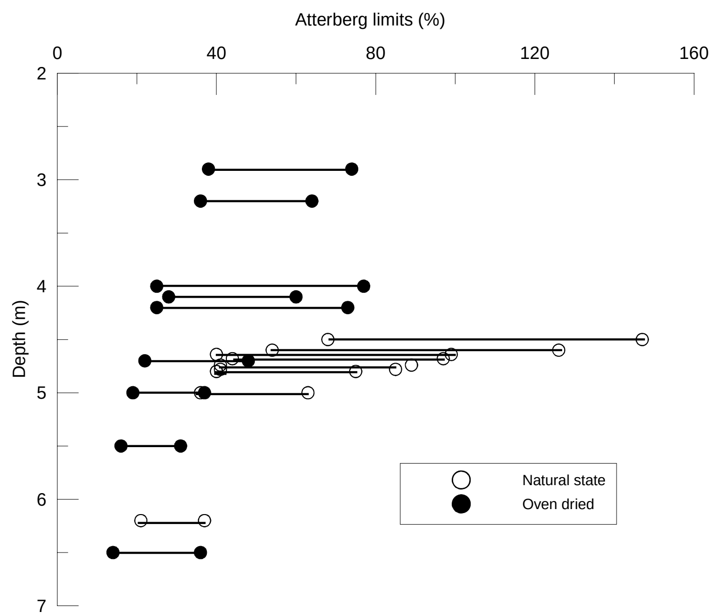

Figure 6. Influence of oven drying on Atterberg limits

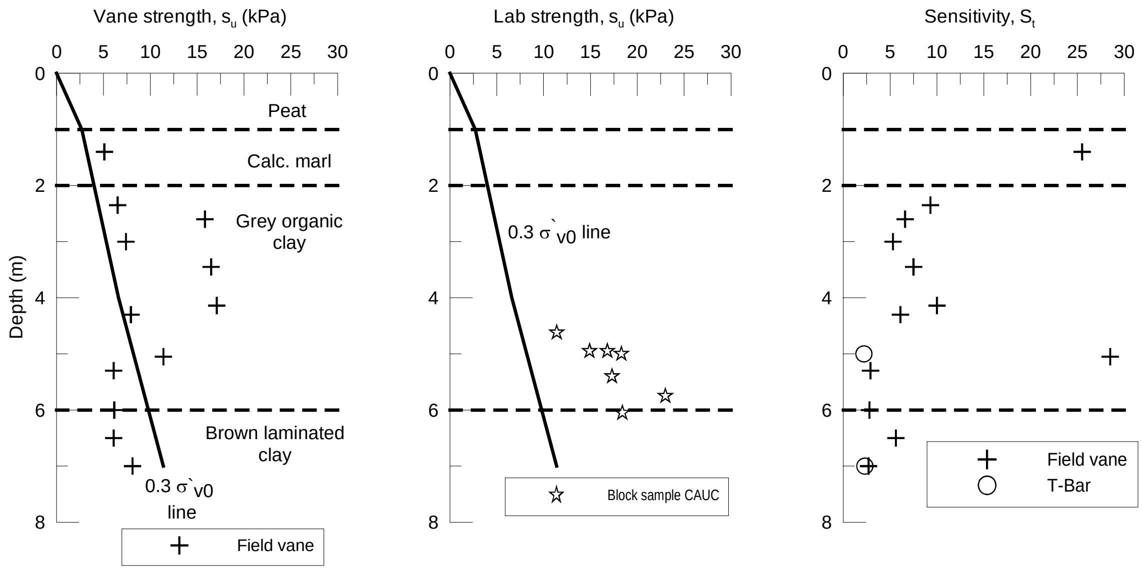

Figure 7. Undrained shear strength and sensitivity.

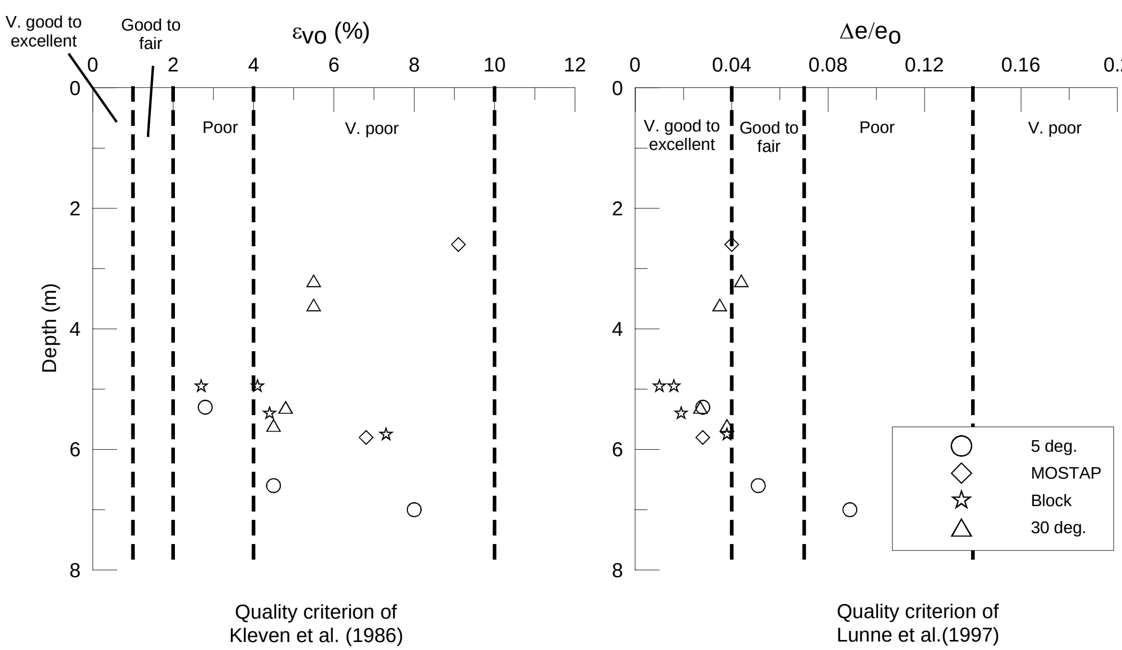

Figure 8. Assessment of sample quality – triaxial tests

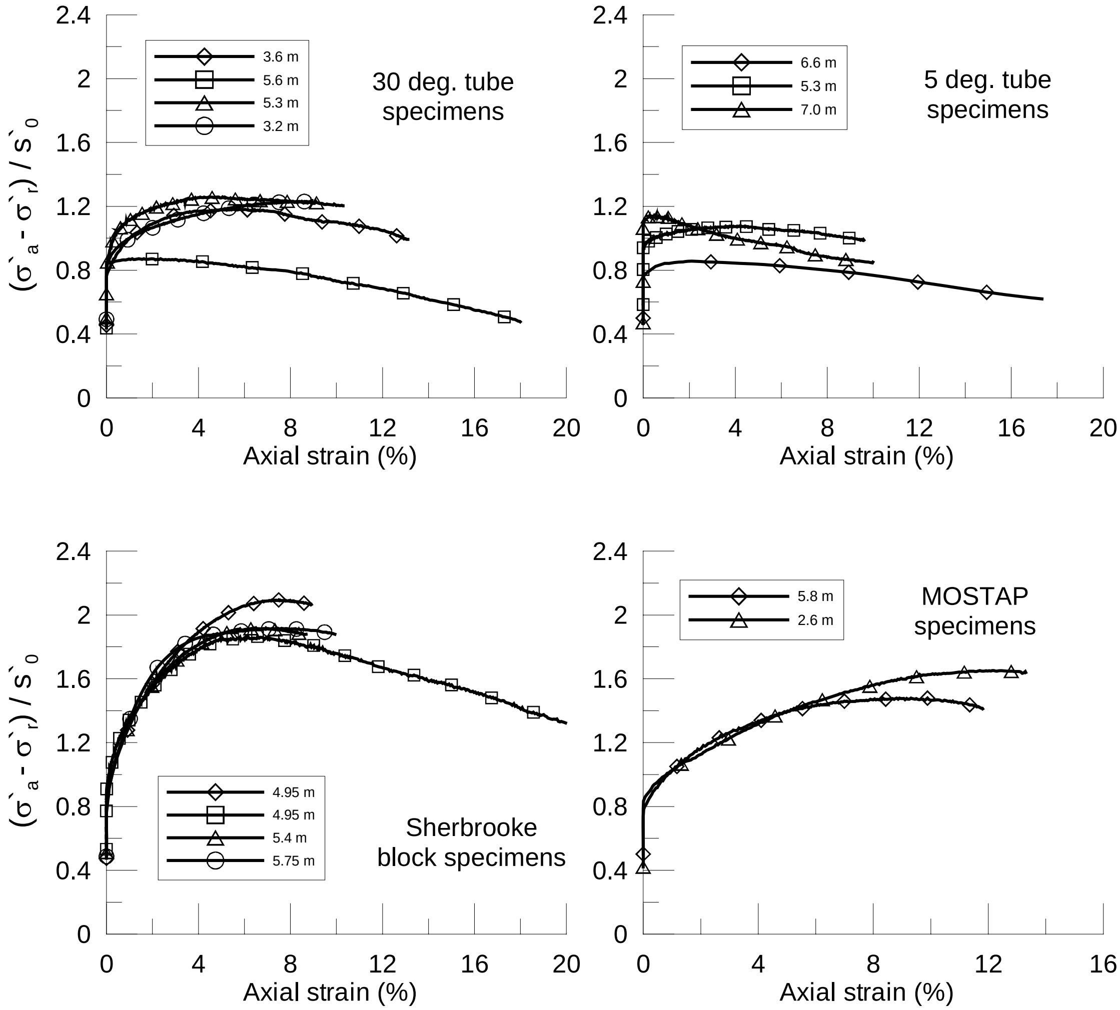

Figure 9. CAUC test deviator stress – strain plots

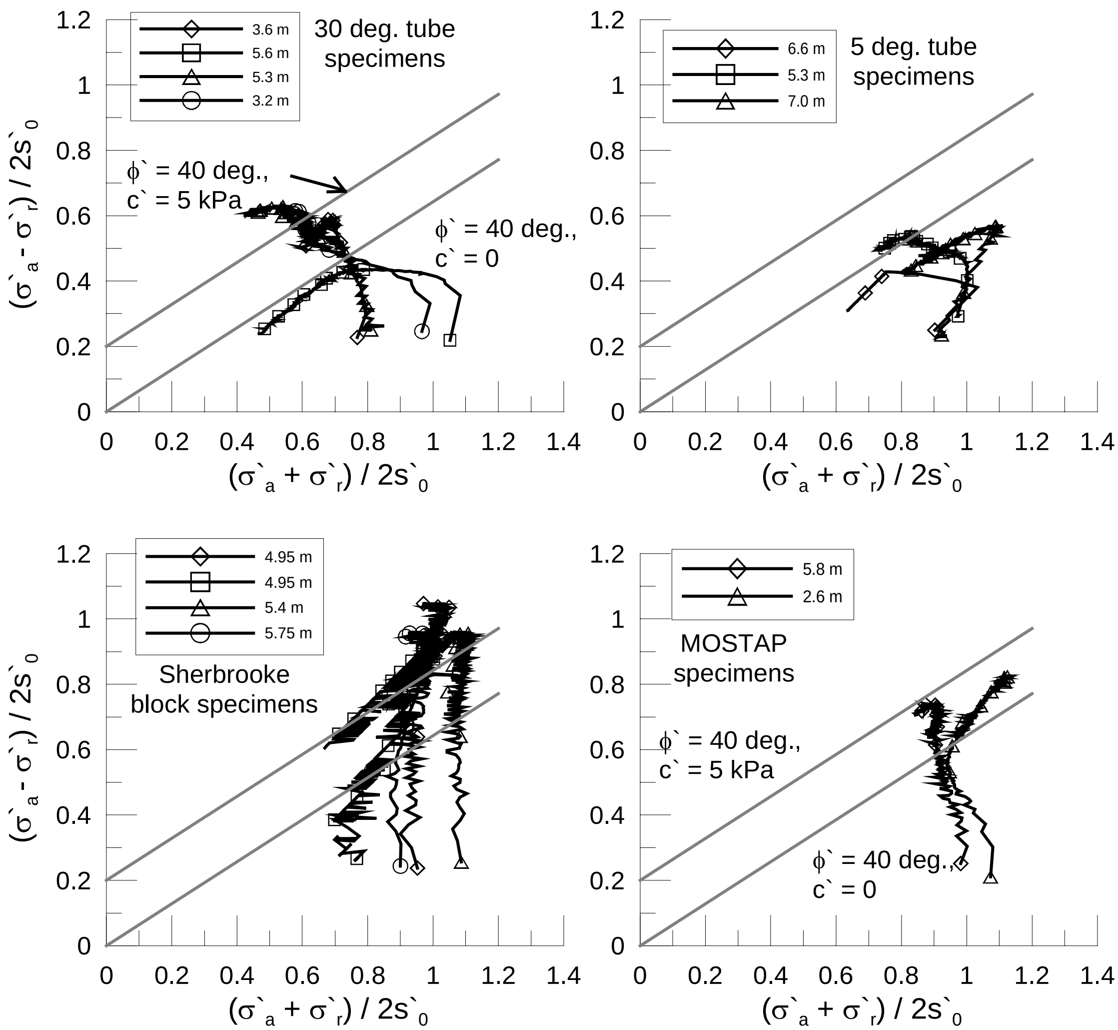

Figure 10. CAUC test – stress path plots

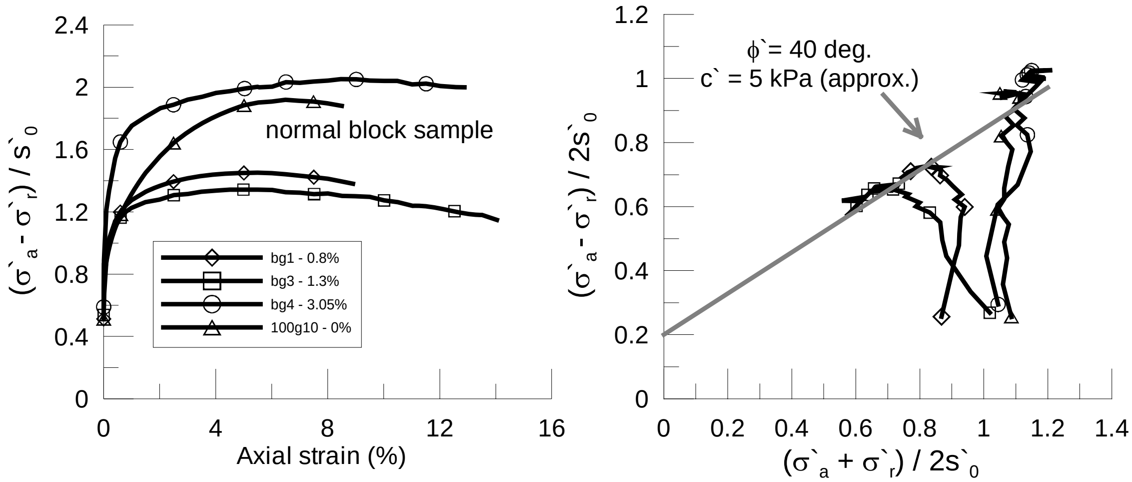

Figure 11. Results of ISA tests on block samples

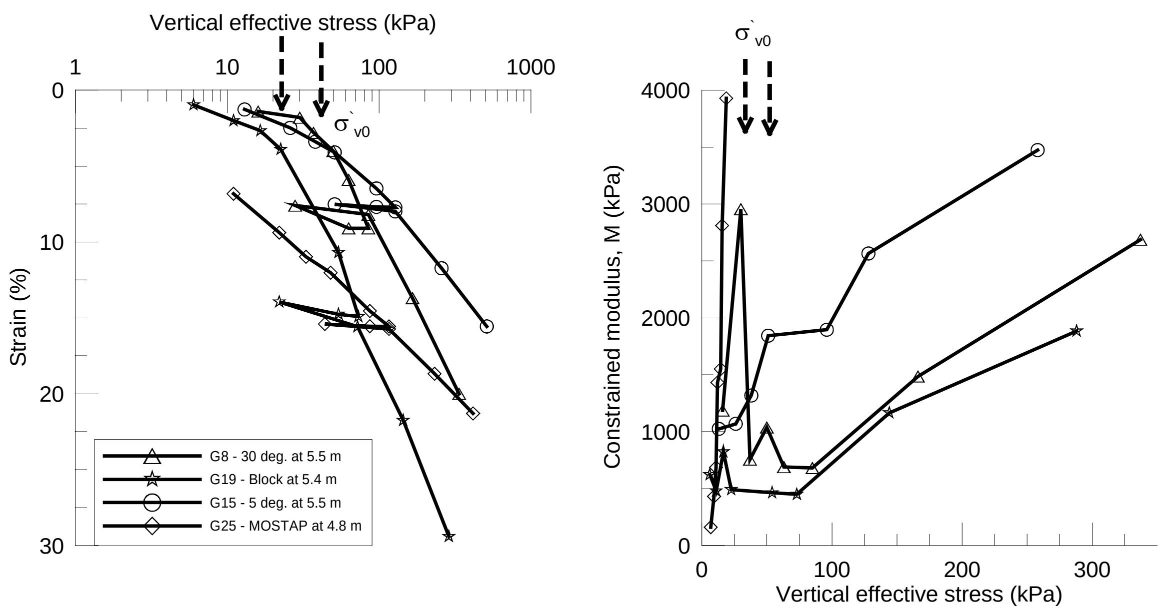

Figure 12. Results of IL oedometer tests

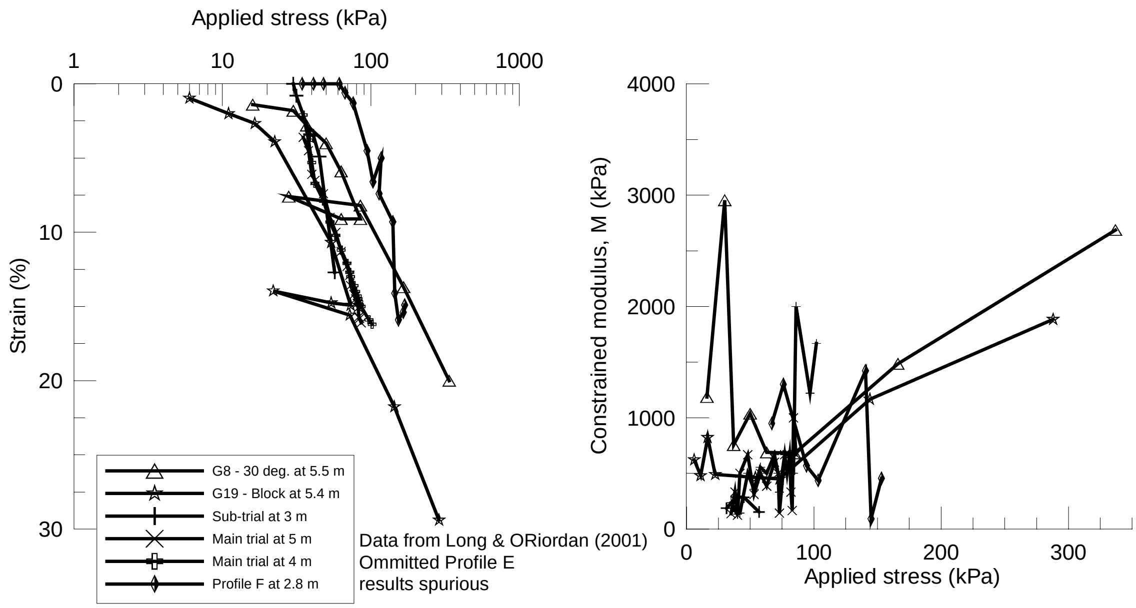

Figure 13. In situ compressibility

DELL+D(D)/Papers/ASTMgrey/Downholefigures.doc