INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

Laboratory Testing of Fissured and Laminated Soils

L'Epreuve du Laboratoire des Sols avec Fissures et Laminés

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SYNOPSIS. The relationship between the nature and distribution of fabric features and the engineering properties of some soils from West Central Scotland are quantitatively examined. The soils tested are stiff fissured glacial lodgement tills, (boulder clays), and soft laminated alluvial silty clays. The data obtained from these investigations demonstrate that the nature and arrangement of particles at all levels of viewing must be considered when determining test specimen representativeness. It is therefore suggested that in such soils representative test data will only be obtained from undisturbed specimens containing 20 or more macrofabric features. In addition, to allow fof the preferred orientation of these features, the imposed direction and mode of strain or water flow in tests and the stress levels applied must all be made compatible with those in the prototype.

INTRODUCTION

Although it is widely appreciated that the influences of laminations and fissures on measured engineering properties are controlled by the differences in the response to changes in applied stress and deformations of the features themselves and the soil matrices in which they are located, little quantitative assessment of this has previously been undertaken. Thus when during major site investigations in West Central Scotland for motorway and urban re-development programmes, the principal soils investigated were found to exhibit pronounced macrofabrics, the opportunity was taken to describe quantiatively these features. The resulting combination of detailed engineering and fabric data then provided an opportunity to study the relationship between the nature of the fabric content and the measured properties of test specimens.

The two major soil groups investigated were stiff glacial lodgement tills formed during the Weichselian glaciation into a series of low hills or drumlins, and soft immediate post-glacial alluvial silty clays associated with the River Clyde Estuary and the sites of former freshwater lakes located between the drumlins of till away from the river. The soil sampling programme was performed using a series of different sampling techniques involving open drive and piston sampling in wet and dry boreholes. Samples taken and laboratory specimens tested ranged in size from 52 mm to 254 mm diameter. The laboratory tests included measurements of undrained and drained shear strengths' compressibility, consolidation rates and permeability. The nature, spatial orientation and distribution of the fissures in the tills were measured in cavities and on block samples using the methods described by Fookes and Denness (1969) and developed by McGown, Sali and Radwan (1974). The laminations in the alluvial silty clays were measured simply in terms of linear frequency and thickness and classified according to their particle size distribution in the same manner as Rowe (1968). The micro fabrics of both soil types were observed using the scanning electron microscope with air-dried specimens, following the techniques developed by Barden and Sides (1971).

The data from these soil fabric and engineering property investigations are now presented and relationships built up between the stress-strain behaviour of test specimens and the nature, relative orientation and number of fabric features they contain. From this the degree of representativeness of test specimens of soils which contain pronounced macrofabrics will be considered and general recommendations for the minimum size and best shape of representative test specimens derived. In addition, the directional dependency of their stress-strain behaviour will be demonstrated.

BASIC PHYSICAL PROPERTIES AND FABRIC DESCRIPTION

(i) Glacial Lodgement Tills.

The tills are characterised by the range of particle sizes they contain, from boulders (> 60 mm) down to clay sizes (< 2 μm) and for this reason they are often called boulder clays. The limits of gradings of the tills are given in Fig. 1.

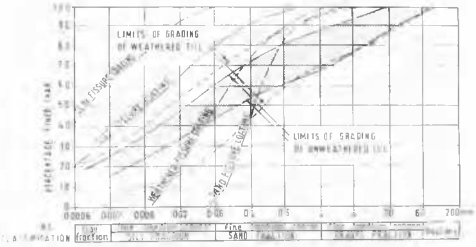

Fig. 1.
The particle size distribution of till mass and of the fissure coatings contained within them.

The tills have a somewhat variable bulk density with a mean value of 2.26 t/m^3 and with a lower average density of 2.03 t/m^3 in the upper weathered layers. The soil is usually saturated with a mean natural moisture content of 12.3% at depth, and 20.3% in the upper layers. It is generally of low plasticity with Atterberg limits varying as shown in Fig. 2.

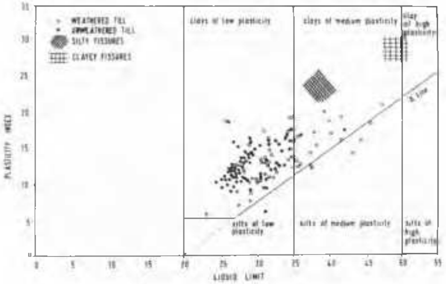

Fig. 2. The plasticity characteristics of the tills and their fissure coatings.

Two distinctive types of fissures are found in the tills. The first is a set of low dip angle bedding features, generally parallel to the natural slope of the drumlin surface directly above their location. These features are coated in a thin layer of either clay, silt or sand, with laminations of silt and clay in a single feature not infrequent. The second type of feature is composed of two or four sets of near vertical, stress relief fissures lying conjugately about the direction of the original ice flow. These fissures are rarely coated and are in fact very rough with asperities in the range 2 to 8 mm whereas the coated fissures have asperitities of only 1 to 4 mm. In the top 2 or 3 m of these soils where significant weathering has occurred, weathering products may be found on most discontinuities, Fig. 1. The spacing of these features is not dependent on their orientation but does tend to increase with depth with significant variations at any particular depth, Fig. 3. The areal extent of the fissures is again somewhat variable but is on average between 200 and 1400 m^2 x 10^{-3}.

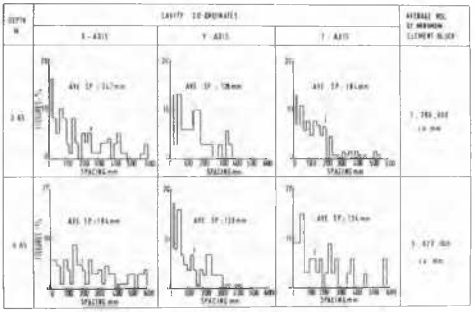

Fig. 3. The spacing of the fissures in the tills.

(ii) Alluvial Silty Clays

The despositional environments of the alluvial soils tested ranged from freshwater to brackish water approaching marine conditions. The freshwater lake deposits investigated were slightly organic, whilst the estuarine clays exhibited low salt contents, suggesting that leaching of these clays may have occurred. Their overall bulk properties are given in Table I.

Table I. Bulk Properties of Alluvial Soils.

Soil Property	Site Location		
	Hurlford Freshwater Lake Clay	Renfrew Lower Estuary Clay	Glasgow Upper Estuary Clay
Water Content (W%)	65	35	24-39
Liquid Limit (LL%)	50	39	42-47
Plastic Limit (PL%)	30	22	22-28
Percentage Clay (%)	52	45	40-50
Specific Gravity (Gs)	2.67	2.67	2.61-2.67
Density (t/m^3)	1.87	1.92	1.86-1.98
Activity	0.47	0.35	0.38-0.5
Organic Content (%)	4.8	1.60	0-1.80
Salt content (Na Cl%)	-	1.50	0.9-1.0

The macrofabrics observed in split and partially air-dried specimens of the soils were dominated by horizontal planar laminations of silt of sand varying in thickness from 0.5 to 5 mm and dustings or silt or clayey silt from 0.1 to 0.5 mm thick. The basic physical properties of the layers and the measured fabric data are given in Table II.

Table II. Macrofabrics of Alluvial Soils.

Soil Property	Site Location		
	Hurlford Freshwater Lake Clay	Renfrew Lower Estuary Clay	Glasgow Lower Estuary Clay
Nature of Matrix	Silty Clay	Silty Clay	Silty Clay
Nature of Laminations	Silt & Sand	Silt	Silt
Nature of Dustings	Silt	Clayey Silt	Clayey Silt
Frequency/ Metre	240	400	340-390
Relative Overall Thickness of Features(%)	24	16	14-16

Detailed examination of these soils at low magnification revealed large numbers of very fine partings. The rapid changes in sedimentation pattern which induced these features are also demonstrated by the overall differences found between the microfabric at different levels in the main matrix in silty clay.

MEASURED PROPERTIES OF LABORATORY TEST SPECIMENS

The natrue of any fissure coatings greatly modifies the influence of fissures on the properties of a soil mass, but in general they are less resistant to applied stresses in both shear and compression and more permeable than the intact soil matrix. Silt and sand laminations in a clay will also increase overall permeability, but they will usually increase resistance of the soil mass to applied stresses in both shear and compression. Of these various effects, those studied in detail in West Central Scotland were the influences of fissures on the shear strength of the till and the influences of laminations on the compressibility and permeability of the alluvial clays.

(i) Influence of Fissures on the Strength of Tills.

In both the undrained and drained shear strength test programmes on the tills, the strength of the single fissures, the intact soil and the large test specimens of the soil were all determined. Testing of the single fissures was undertaken in the shear box, the intact soil was tested by the small laboratory vane and in the triaxial apparatus, using lubricated end platens and samples with a height to diameter ratio of 1:1.

McGown, Sali and Radwan (1974) and McGown and Radwan (1975) found that the undrained shear strength of fissures may be much less than that of the intact soil, sometimes only one sixth, thus as the size of test specimens used increases and the probability of inclusion of numbers of fissures increases so the possibility of specimen variability decreases until the representative strength of the soil mass is approached, Fig. 4. McKinlay et al (1975), in fact, found for the tills, that for 10 per cent variability of undrained shear strength the diameter of triaxial test specimens was 6 to 40 times the minimum fissure spacing. This range reflects to some extent the variation in spacing and areal extent of the fissures but in particular reflects the differences in the fissure coatings. Re-analysis of data from other fissured soils reported by Simons (1964), Lo (1970), and Bishop and Little (1967) confirms these findings with specimen diameters of 8 to 22 times minimum fissure spacing for 10 per cent variability of undrained shear strength. On this basis a minimum specimen diameter of 20 times minimum fissure spacing was recommended by McKinlay et al (1975).

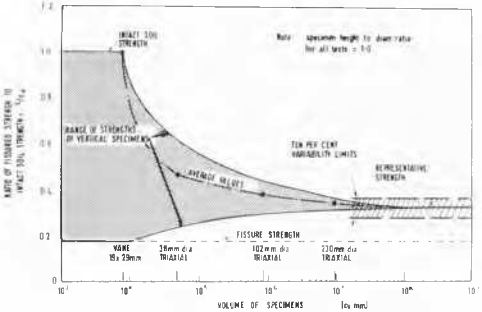

Fig. 4. The relationship between the undrained shear strength and volume of till test specimens.

The relationship between size and measured shear strengths so determined were limited to any particular direction and mode of strain. When triaxial tests were conducted on large specimens approaching representative size, (225 mm diameter in the tills), taken from samples obtained in several different spatial orientations, the influence of the fissure sets, in their different but definite directions, was such as to induce three dimensional anisotropy, Fig. 5. Thus two dimensional relationships between strength and size as proposed by Bishop (1966) and Lo (1970) are inappropriate in this case. The direction of the plunge of the test specimen must be included as shown in Fig. 6.

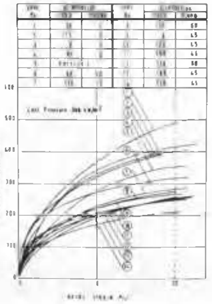

Fig. 5. The stress-strain curves for till test specimens sampled with a range of trends and plunges.

The Maximum variation in undrained strength of large triaxial test specimens taken in various orientations was ± 50 per cent of the undrained strength of a large vertically oriented test specimen and the drained angle of friction ranged from 17 to 33 degrees, Radwan (1975). The explanation of these large variations lies the differences between the nature of the various fissure sets and the nature of the intact soil and therefore the differences in their drained shear strength behaviour.

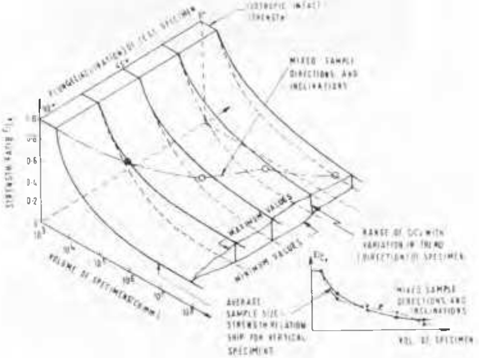

Fig. 6. A three dimensional representation of the undrained shear strength variability of fissured till.

The drained shear strengths of the fissures in the tills were found to be extremely difficult to measure because of the roughness and limited areal extent of the fissures. Such drained shear strength measurements as were possible could, however, be directly correlated to the nature of the fissure coatings, as shown in Table III.

TABLE III. Drained Shear Strength Parameters of Tills.

Soil Feature	Measured Angles of Friction $\emptyset'$	Plasticity Index	Predicted angles of Friction *	
			$\emptyset'_{peak}$	$\emptyset'_r$
Intact Soil	28-33	15	28	26
Clean Fissure	25-38+	-	-	-
Sandy Fissure	38-40	-	-	-
Silty Fissure	22	24	25	20
Clayey Fissure	17	29	22	12

* After Vaughan and Walbancke (1975) Fig. 10

+ Greatly influenced by presence of stones.

The granulometric nature of the coatings and their plasticity characteristics were given in Figs. 1 and 2 respectively. When these data are used in the relationship between plasticity index and peak and residual angles of friction ($\emptyset_{peak}$ and $\emptyset'_r$ respectively), suggested by Vaughan and Walbancke, (1975), Fig. 7, some interesting predictions of fissure and intact strengths are possible, Table III. As it is possible that some movement along the coated fissures has occurred during deposition, although not necessarily sufficient to reduce the value to $\emptyset'_r$, the values of predicted and observed drained angles of friction are entirely compatible. Thus there is some evidence to support the observed variations in stress-strain responses of the various fissure types and the intact soil.

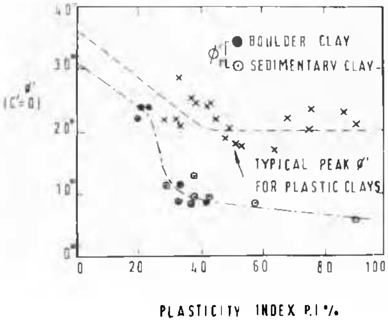

Fig.7. The relationship between drained peak and residual angles of friction and plasticity index (Vaughan and Walbancke, 1975)

(ii) Influence of Laminations of the Compressibility and Permeability of Alluvial Clays.

The laboratory compressibility and permeability testing on the soft alluvial clays was undertaken in three sizes of Rowe cells, 76, 152 and 254 mm diameter which included samples of 19, 42 and 74 mm thickness respectively. Both axial and radial flow consolidation tests were executed on these. McGown et al (1974) and McGown et al (1975) reported the disturbance to the microfabric of the soils during sampling and in the latter study reported that this disturbance altered the shape of the void ratio effective stress curves with reduction in the initial void ratio, masking of the maximum past pressure and reduction of post preconsolidation compressibility, Fig. 8.

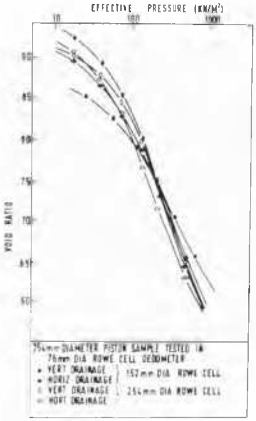

Fig. 8. Typical void ratio-effective pressure curves for laminated silty clay tested in a variety of sizes.

Generally it was found that as the test specimen diameter increased, the influence of disturbance decreased. In fact, improved macro-fabric representativeness was also obtained due to the increasing specimen thickness obtained with Rowe cell diameter increase. This was also noted by McGown et al (1975) but not quantified. The data from these previous investigations have now been re-analysed following further detailed investigations in these studies. The effects of the macrofabric representativeness in the test specimen has been established by monitoring the shape of the individual void ratio effective stress curves in the same three ways devised by McGown et al (1975) but in this case these shape factors have now been directly related to the number of laminations present in the specimens from which the curves were obtained.

The first shape factor is based on a definition of relative degree of disturbance after that suggested by Schmertmann (1955) which attempts to quantify the peakiness of the e-log p' curves, Fig. 9 (a). From Fig. 9 (b) it is clear that the peakiness of the curves is more pronounced as the number of fabric features in the specimen increases. Thus macrofabric representativeness influences the shape of the curves in the same way as the previously recognised microfabric disturbance.

Accepting Schmertmann's (1955) suggestion that the straight line portions of the e-log p' curves of a clay when undisturbed and remoulded pass through a common point at 40 per cent of the initial void ratio, an assessment of the alteration of the measured preconsolidation stress can be obtained in the manner put forward by Terzaghi and Peck (1967), Fig. 10 (a). From this second shape factor, Fig. 10 (b), both microfabric disturbance and macrofabric representativeness may be clearly seen to have important influences on the shape of the e-log p' curve.

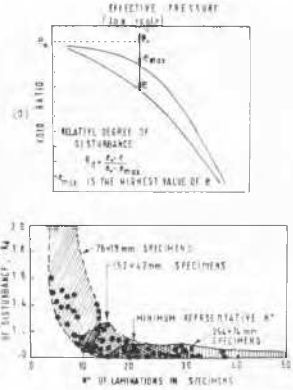

Fig. 9. The relationship between relative degree of disturbance and the number of laminations in test specimens.

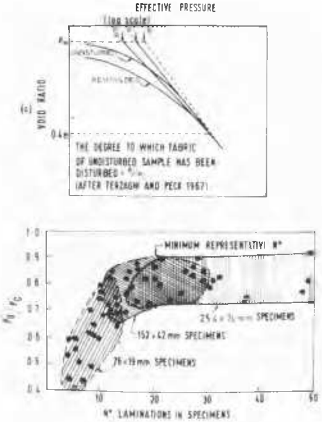

Fig. 10. The relationship between the degree to which fabric has been disturbed and the number of laminations in test specimens.

Again from Schmertmann (1955), numerous virgin or field slopes (C_{cv} field) of the straight line portion of the e-log p' curve can be obtained from the test data derived from the various test specimens. Taking the least disturbed soil for all sizes of specimen to be the steepest field slope, ($C_{cv\ Best}$) and dividing it by all other values (C_{cv}), provides the third curve shape factor. From the plot of this data in Fig. 11, it may be seen that as with the other shape factors, the dual effects of disturbance and representativeness are influencing the shape of the curve.

Taking all three shape factors together, McGown et al (1974) and McGown et al (1975) suggested that with respect to microfabric disturbance a minimum sample and test specimen diameter of 152 mm was required in these soils using the methods of sampling and testing available in the area. From the re-analysis of the data now undertaken the number of macrofabric features required for representativeness is shown to be a minimum of 20 or so. This number is much more definite than the numbers of fissures required for representativeness, referred to in the previous section, principally because the spacing of the laminations is much more regular than for the fissures and the laminations have large continuous areal extent. That 20 laminations are required is, however, evidence of a certain degree of irregularity in laminae spacing and the variations in the microfabrics within the various laminae and soil matrix layers as indicated in Fig. 12.

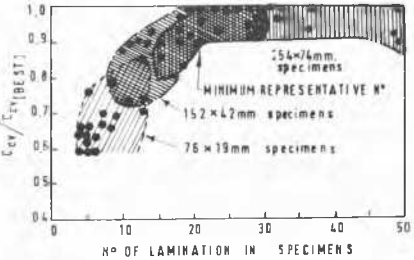

Fig. 11. The relationship between virgin slope shape factor and number of laminations in test specimens.

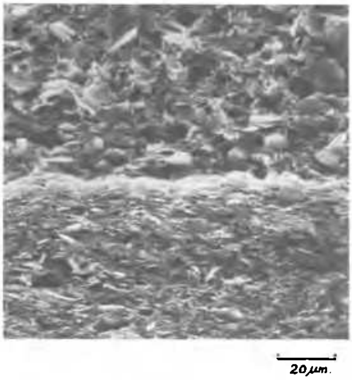

Fig. 12 Scanning electron micrograph of a vertical section of laminated silty clay.

Further confirmatory evidence of the macrofabric representativeness effects are given when the permeability ratios obtained from the vertical and radial drainage tests are plotted against fabric content as shown in Fig. 13. Once again the scatter of data is significantly reduced when 20 or more laminae are included in the specimen. Microfabric disturbance effects are nevertheless demonstrated in this plot but are again shown not to completely over-ride macrofabric representativeness.

Fig 13. The relationship between the permeability ratio and the number of laminations in test specimens.

CONCLUSIONS

The soil fabric and engineering property investigations on these soils from West Central Scotland have demonstrated quantitatively that the nature and arrangement of particles at all levels of viewing from micro to macro level must be considered when determining test specimen representativeness and thereby attempting to obtain representative test data.

In previous investigations the influence of the nature and microfabric of the fissure coatings in the tills was not fully recognised. The data now presented on the drained strength of the various coatings materials, however, clearly demonstrate that the distinction between the nature of the various fissure coatings is of critical importance in determining the shear strength behaviour of the fissured soil mass. Although not directly dealt with, it follows that the deformation and permeability of fissured soil masses will also be controlled by the nature of the fissure surfaces and coatings. The variability of these coatings and their limited areal extent have also been suggested as prime factors in producing the wide varation in representativeness in tills.

For the alluvial clays, a full description of the importance of the disturbance of the microfabric has, previously been reported but the present investigation has demonstrated that the variability of spacing and thickness of laminations and variability of microfabric within laminations and within the soil matrix, requires that the number of fabric features in specimens must also be considered. The previous work of Rowe (1968, 1971) was principally directed towards the use of larger diameter specimens of specific height to diameter ratios which certainly reduced the microfabric disturbance effects, but did not encourage consideration of the number of laminations contained in the test specimens and therefore macrofabric representativeness. Most test apparatus, like the Rowe consolidation cell, have sufficient in built flexibility that variable specimen thickness may be used. From the data analysed, 20 or more laminations should be included in compressibility and permeability test specimens. Although not specifically referred to, the shear strength of these soils will no doubt be similarly influenced by macrofabric representativeness.

From both the till and alluvial clay data, the definite preferred orientation of the soil fabric must be considered when testing. This was particularly demonstrated for the tills but is equally important in the alluvial clays. Thus the need to ensure compatibility of test specimens with the mode of strain or water flow in the prototype is critical. The stress level at which testing takes place is equally important, for with variations in the nature of the various fabric features and the soil matrix measured in these soils, quite different responses to increase or decrease of stress level are to be expected.

Essentially fissures and laminations have very similar influences on soil mass behaviour, however, fissures tend to be much more variable, in nature, orientation, spacing and areal extent and can therefore lead to a greater degree of variability in the soil mass. Therefore, in soils containing laminations or fissures, the present study concludes that representative test data will only be obtained when test specimens are undisturbed, contain a sufficient number of macrofabric features and that they are tested in a direction and mode of strain with a water flow pattern and at a stress level which are compatible with the prototype. Many standard equipment dimensions, sample shapes and test procedures may fail to meet this recommendation.

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