"THE EFFECT OF FISSURES ON THE SHEAR STRENGTH OF BLUE LONDON CLAY" *

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Synopsis. The present paper deals with the effect of fissures on the shear strength of Blue London clay. During tunneling operations in London's underground, samples were collected from the depth of 30 m. and consequently tested.

The laboratory results indicates a remarkable difference in shear strength, which attributed to the inclination and orientation of the fissures. The paper also describes a summary of existing theories and observations and an attempt was made to emphasize the meaning of fissures existence in clay for certain Geotechnical situations.

Περίληψις. Ἀπὸ μακροῦ χρόνου διεπιστώθη ἡ ἐπίδρασις τῆς ὑπάρξεως μικρορωγμῶν ἐντὸς τοῦ LONDON CLAY εἰς τὰς ἰδιότητας ἀντοχῆς αὐτοῦ. Τὸ πρόβλημα προσεγγίσθη θεωρητικῶς, ἀλλὰ κυρίως ἐκ τῶν ἐργαστηριακῶν ἀποτελεσμάτων διαφόρων δοκιμῶν κατέστη δυνατὸν νὰ ἐξαχθοῦν γενικωτέρας φύσεως συμπεράσματα. Οὕτως, ἡ ἀντοχὴ τοῦ ἐν λόγῳ ὑλικοῦ θεωρεῖται ὡς συνάρτησις τῶν μορφολογικῶν χαρακτηριστικῶν τῶν ρωγμῶν, τοῦ χρόνου παραμονῆς τῶν δοκιμίων ἐντὸς τῶν πειραματικῶν διατάξεων, ἐκ τοῦ βάθους ἐκ τοῦ ὁποίου τὰ δοκίμια προέρχονται καὶ ἐκ τοῦ προσανατολισμοῦ τοῦ ἐπιπέδου τῶν ρωγμῶν. Ἐν προκειμένῳ ἐπεσημάνθη ἐργαστηριακῶς, ἡ διαφορὰ εἰς τὴν τιμὴν τῆς ἀντοχῆς εἰς διάτμησιν τοῦ LONDON CLAY, ἀναλόγως τοῦ προσανατολισμοῦ τῶν δοκιμίων — καὶ κατὰ συνέπειαν τῶν ρωγμῶν — ὡς πρὸς τὴν στρῶσιν των. Ἡ παρατηρηθεῖσα διαφορὰ εἰς τὴν διατμητικὴν ἀντοχὴν συμφωνεῖ πλήρως :

α) Μὲ τὰς παρατηρήσεις τοῦ AGARWAL ὡς πρὸς τὸν προσανατολισμὸν τῶν δοκικιμίων, καὶ

β) Μὲ τὰς ὑπὸ τοῦ MARSLAND προταθείσας τιμὰς διατμητικῆς ἀντοχῆς διὰ τὸ βάθος ἐκ τοῦ ὁποίου τὰ δείγματα ἐλήφθησαν.

Ἐκρίθη, ἐπὶ πλέον, σκόπιμος ἡ παράθεσις ἐν συντομίᾳ τῶν κυριωτέρων ἀπόψεων καὶ παρατηρήσεων διαφόρων ἐρευνητῶν, ὡς καὶ ἡ σημασία τῆς ὑπάρξεως τῶν μικρορωγμῶν εἰς τὰ καθαρῶς ἐφηρμοσμένα γεωτεχνικὰ προβλήματα.

INTRODUCTION

The existence of fissures in clay and their influence on the strength parameters have been ascertained years ago from the pioneers K. TERZAGHI (1936) and A. SKEMPTON (1948).

When TERZAGHI examined the stability of clay slopes his attention dropped on joints and fissures as well as on the mechanics of the process of softening due to these small structural features.

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* Μ. Λ. ΜΥΡΙΑΝΘΗ — «Ἡ ἐπίδρασις τῶν μικρορωγμῶν ἐπὶ τῆς ἀντοχῆς εἰς διάτμησιν τοῦ London clay».

Nevertheless landslides in such clay occur as soon as the shearling stresses exceed the average shearing resistance of the fissured clay. In fact the softening phenomenon and the decreasing of the average shearing resistance from a reasonable value during the excavation time to comparatively small values at the time of landslide have become existing problems for either engineers or geologists.

However, a large scale effort was made to find out, as detailed as possible, the degree of influence of fissures as well as the decreasing of the strength of the clay in open excavations and cuttings due to softening of the clay along fissures.

THE GEOLOGY OF THE LONDON BASIN

The clay which underlies most of the London Basin is a stiff, fissured, overconsolidated, blue-grey clay, and was called the «London clay» by W. Smith in 1812. The sediments were deposited under marine conditions in the Eocene period, and subsequently the Claygate Beds, followed by the Bagshot, Bracklesham and Barton Beds were deposited. These were all predominantly sandy beds with occasional clay layers. However, uplift and erosion in the late Tertiary and Pleistocene have removed most of the overlying beds and half to two thirds of the London clay itself; and only in a few areas do any of the overlying beds remain (BISHOP et al, 1965).

Much of this erosion took place at intervals during the Pleistocene glaciations, and following each period of down cutting, terrace gravels were deposited by the Thames. The alluvium which overlies the Flood Plain gravels is a recent post-glacial material and contains Neolithic as well as Roman remains. The amount of material removed by erosion varies from place to place. SKEMPTON and HENKEL (1957) quote a preconsolidation load of 2145 KN/m^2 for the central London area suggesting a removal of 170 - 230 m of material. The London clay itself consists of a lower sandy clay, varying from 0 - 3 m thick, known as the Basement Bed. This is overlain by a blue-grey clay, varying from 30-170 m thick, which is the London clay proper, and finally near the surface is the brown clay, varying from 0 - 10 m thick. The sands and gravels previously mentioned overlie the London clay in many areas, as does alluvium near the Thames, and soft marsh clay and peat near the sea. The upper layer is yellow-brown near the surface to grey-brown at depth due to oxidation of the iron salts in the blue clay, probably when the ground water level was low. The structure of the London clay on a regional scale has the form of a very gentle syncline with some minor folding in places (WARD et al, 1959), although dips of more than 3 degrees are rare. This brief description of London's Geology — based on P. Grey's dissertation (1972) — was necessary in order to realize the material in which the test was carried out.

THEORIES AND OBSERVATIONS

The existence of discontinuities is characteristic of a heavily overconsolidated clay (TERZAGHI, 1936) and joints and fissures are thought to have been formed by stress release as a great deal of the overburden was eroded. This is in agreement with field observations as the mean size of the fissures decreases and the number per unit volume increases as the upper surface of the clay is reached (SKEMPTON et al, 1969).

Relating to the softening of the clay along fissures SKEMPTON (1964) suggests that the shear stresses field tends to concentrate in joints and fissures creating a concourse field with a resultant stress greater than the shear strength of the clay. Obviously, this occurrence leads to the progressive failure. Yet, it might be taken into account that these discontinuities are local anomalies of the clay concerning it as a solid mass and their strength, is less than the strength of the adjacent material.

Opinions of many authors suggesting the dependence of strength value from the sampling technique and from the length of time that the clay remains in the sample tube under particular stresses. Thus, (WARD et al, 1959) showed that the extraction of the samples from the ground can lead to considerable disturbance and hence weakening of the material (WARD et al, 1965) also pointed out the time factor, proving that strengths obtained from plate loading tests 4 - 8 hours after excavation were only 85 % of the strengths measured after 0.5 hours, and that the strengths measured after 25 days were only 75 % of the initial strength.

Many times the strengths determined in the laboratory are consistently different than those in the field. Although, the observations indicate this discord, undoubtedly, a useful index is the ratio of overall strength for short-time periods to the strength measured in laboratories after careful sampling and specimen preparation. The range of values of the above mentioned ratio varies from 50 % to 75 % in case of large-scale loading tests in situ. AGARWAL (1967) investigated the problem of size and orientation of samples and found that generally the strength of the London clay decreases with increasing size of sample, and that the strength of sample varies considerably with respect to the orientation of the sample ; horizontal samples being the strongest and vertical being the weakest. This conclusion is in a good agreement with the present work, when we verify Agarwal's observation and also found that this is still valuable even in a depth of 30 m. where the overburden ranges in considerably higher values. As far as we were concerned, three large projects were carried out to investigate the effect of joints and fissures in the London clay.

The first project took place during the construction of the M1 motorway near Edgware in the North part of London with results summarized by SCHUSTER (1965).

The second one was made at Wraysbury during the construction of a new reservoir with results published by (SKEMPTON et al, 1969).

The last projecd was baset on the detailed investigation made in a deep shaft at Ashford Common (WARD et al, 1965) which concerned the first comprehensive study of the London clay in depth.

Comparison between the results of the laboratory and in situ tests indicated that the lower values measured on small specimens, in the laboratory, were more representative of the large-scale strength of the clay than the average values from such tests (A. MARSLAND, 1971).

LABORATORY TESTING ON STIFF FISSURED LONDON CLAY

During tunneling operations at the first stage of a new underground railway construction in London's underground system we had the opportunity to collect samples from the tunnel's working face. The

TEST RESULTS

GROUP	σ_3	$\frac{\sigma_1+\sigma_3}{2}$	$\frac{\sigma_1-\sigma_3}{2}$	σ_f KN/m²	(STRAIN)$_f$ %	C KN/m²	φ DEGREES
VERTICAL	490	743	253	506	4.33	235	0° 26′
	650	898	249	497	8.00		
	700	945	245	489	4.85		
	780	1097	317	634	5.90		
HORIZONTAL	400	812	412	825	4.33	400	0° 26′
	440	893	452	905	5.38		
	620	985	364	729	4.85		
	760	1176	416	833	5.38		

depth in which the cavity was located was estimated at about 30 m. and the overburden pressure for that depth and clay was approximately 686 KN/m². In that depth the clay was blue, stiff and fissured. The fissures were very small between 1.5 and 4.5 cm. in size with strike directions not showing any preferred orientation and with dips that tended to concentrate at inclinations to a bedding of less than 15^0 and between 75^0 and 90^0.

The fissures in shape are plane, curved or irregular, and have generally rough texture. At least we should suggest that this was a predilection of a disposition in sub parallel to bedding horizons of these fissures. In that depth of 30 m. the clay was in a more overconsolidated state.

Laboratory results show the following characteristics of this clay,

Moisture content:	25 %
Bulk density:	1935 Kg/m^3
Liquid limit:	76 %
Plastic limit:	33 %

Consolidation (loading intensity): $1700 \sim 1800$ KN/m^2

Permeability (falling head): $1.9 \sim 2.2 \times 10^{-9}$ mm/s.

However, samples on 38 mm diameter specimens from both horizontal and vertical directions, in respect of ground surface, were collected in an attempt to point out the effect of inclination and orientation of the fissures in their shear strength.

Provision was made for testing the samples, as soon as was possible, avoiding any influence due to time factor. Hence, we hopingly beleive that no serious extension of the fissures within the specimens took place during storage. Unfortunately there is a lack of data on the changes in strength that occur during very short periods of storage under reduced stresses (A. MARSLAND, 1971).

The procedure for the preparation of the 38 mm in diameter undisturbed samples for undrained triaxial compression tests using different lateral pressure values was the ordinary one. In order to obtain valuable results we used cell pressures in the vicinity and up to overburden. During the series of tests the samples were not allowed to drain — of course — and the average moisture content was kept constant. The samples were compressed at rates of strain of about 2 per cent. The resulting Mohr stress diagrams are given in (Figures 1 and 2).

RESULTS AND CONCLUSIONS

As it appears from the table of results, a set of eight undrained triaxial compression tests were made with lateral pressure values ranging from 400 to 780 KN/m^2. The samples were divideded into two main

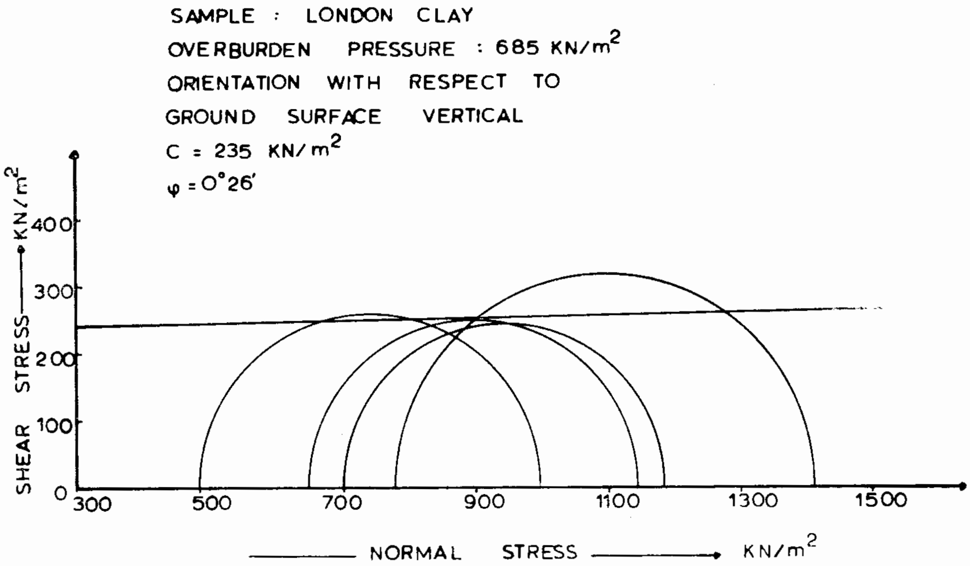
SAMPLE : LONDON CLAY
OVERBURDEN PRESSURE : 685 KN/m2
ORIENTATION WITH RESPECT TO
GROUND SURFACE VERTICAL
C = 235 KN/m2
φ = 0°26′
SHEAR STRESS ——→ KN/m2
400
300
200
100
0
300
500
700
900
1100
1300
1500
—— NORMAL STRESS ——→ KN/m2

Fig. 1.

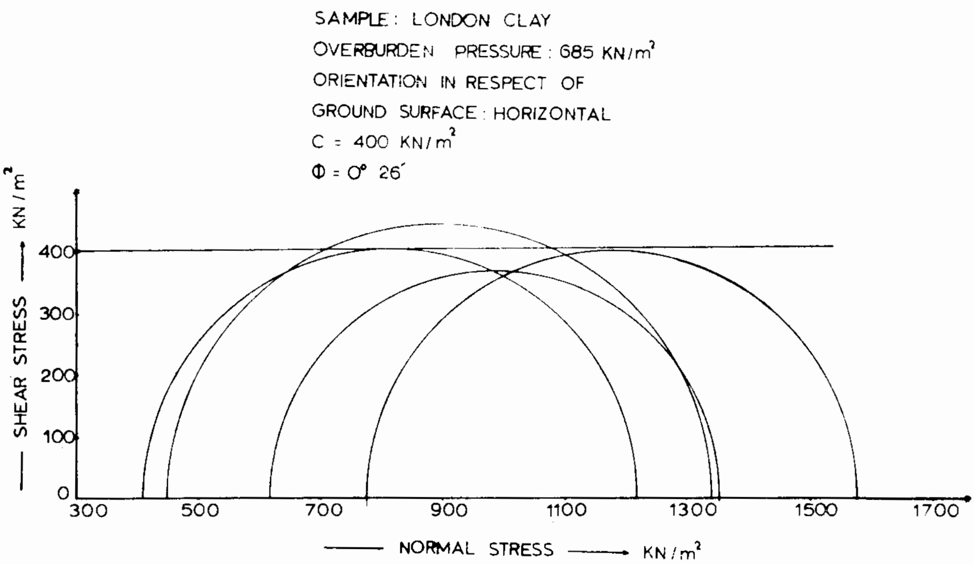
SAMPLE: LONDON CLAY
OVERBURDEN PRESSURE : 685 KN/m2
ORIENTATION IN RESPECT OF
GROUND SURFACE : HORIZONTAL
C = 400 KN/m2
Φ = 0° 26′
— SHEAR STRESS ——→ KN/m2
400
300
200
100
0
300
500
700
900
1100
1300
1500
1700
—— NORMAL STRESS ——→ KN/m2

Fig. 2.

groups one called horizontal and another one called vertical. Saying horizontal group means that the samples orientation in respect of ground surface was horizontal and vice versa.

We assumed that the sample volume remains constant and that the area of the sample increases uniformly as the length decreases. The area of sample was calculated easily using the above assumption of proportionality. From the graph of compressive stress against strain, the maximum

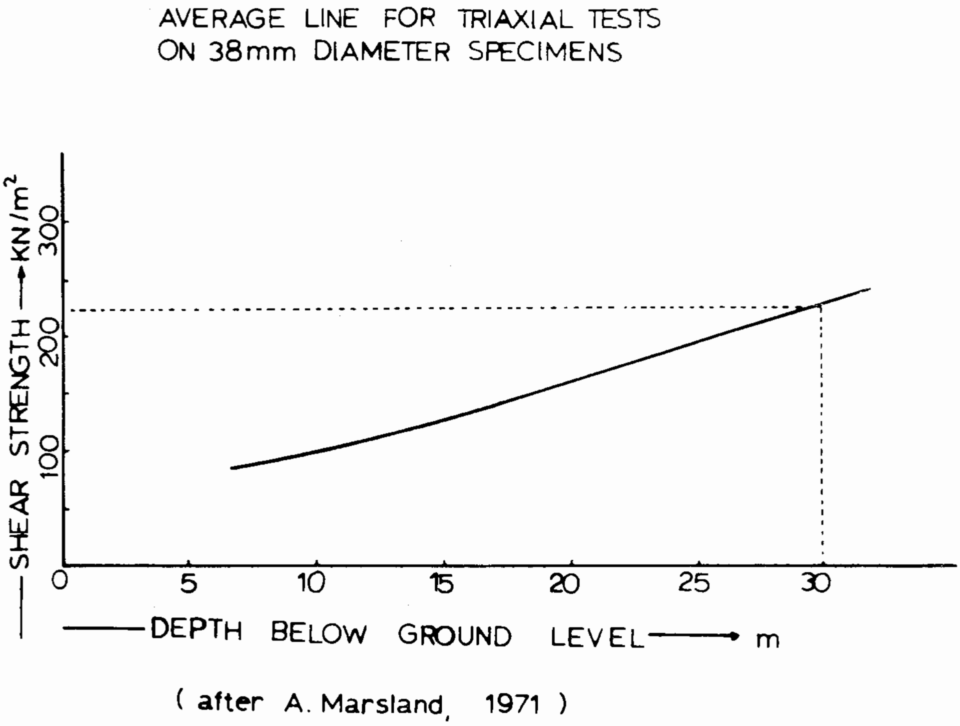

Fig. 3.

compressive stress — that at failure — deduced and the stress results from four cell pressures for each group were plotted on a Mohr stress diagram (Figures 1 and 2) which gave the condition of failure. The shear strength for the vertical group was estimated at 235 KN/m². The obtained value was in good agreement with that proposed by Marsland (Figure 3) using a loading test on a 865 mm diameter plate made in unlined boreholes at North London, and for the same depth. Regarding the horizontal group we notice a shear strength value of 400 KN/m². It should be noted that this remarkable difference between the two shear strength values is primarily attributed to the effect of inclination and orientation

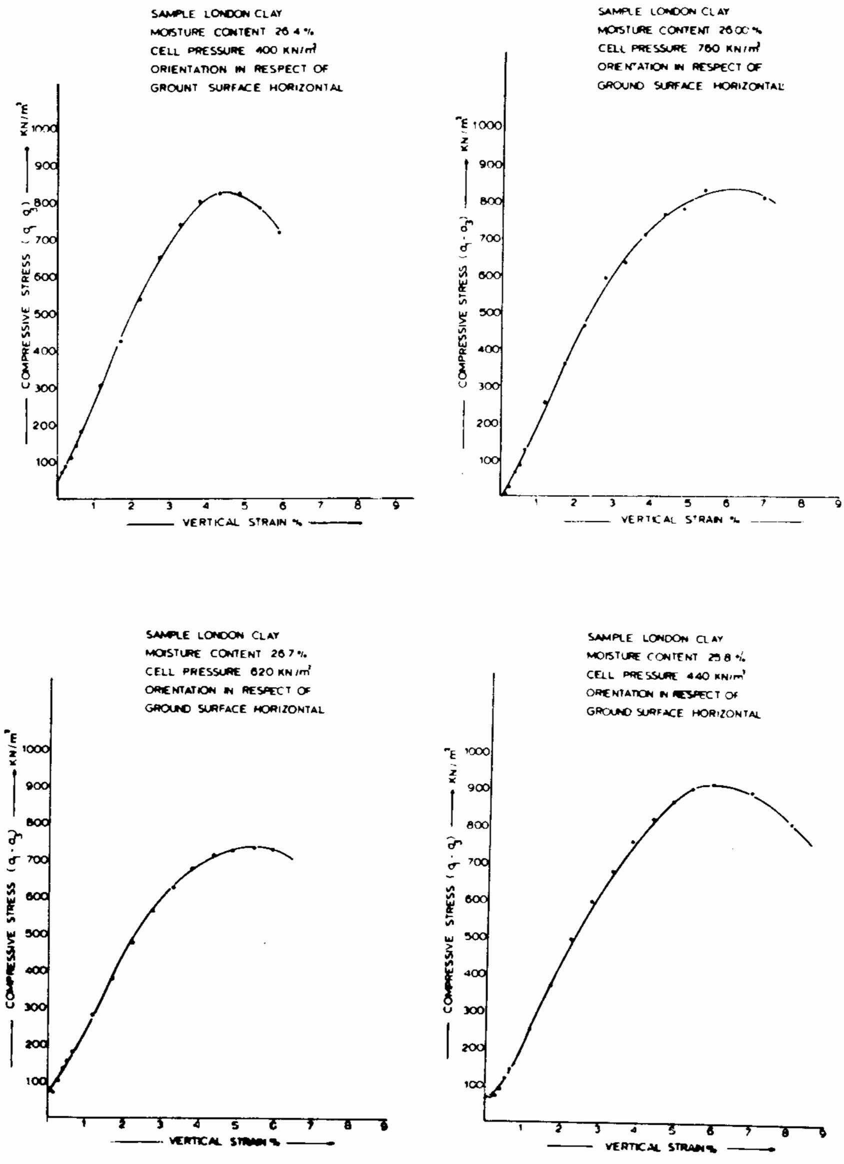
SAMPLE LONDON CLAY
MOISTURE CONTENT 26.4 %
CELL PRESSURE 400 KN/m²
ORIENTATION IN RESPECT OF
GROUNT SURFACE HORIZONTAL
COMPRESSIVE STRESS (q - q3) KN/m²
VERTICAL STRAIN %
SAMPLE LONDON CLAY
MOISTURE CONTENT 26.00 %
CELL PRESSURE 760 KN/m²
ORIENTATION IN RESPECT OF
GROUND SURFACE HORIZONTAL
COMPRESSIVE STRESS (q - q3) KN/m²
VERTICAL STRAIN %
SAMPLE LONDON CLAY
MOISTURE CONTENT 26.7 %
CELL PRESSURE 620 KN/m²
ORIENTATION IN RESPECT OF
GROUND SURFACE HORIZONTAL
COMPRESSIVE STRESS (q - q3) KN/m²
VERTICAL STRAIN %
SAMPLE LONDON CLAY
MOISTURE CONTENT 25.8 %
CELL PRESSURE 440 KN/m²
ORIENTATION IN RESPECT OF
GROUND SURFACE HORIZONTAL
COMPRESSIVE STRESS (q - q3) KN/m²
VERTICAL STRAIN %

Fig. 4.

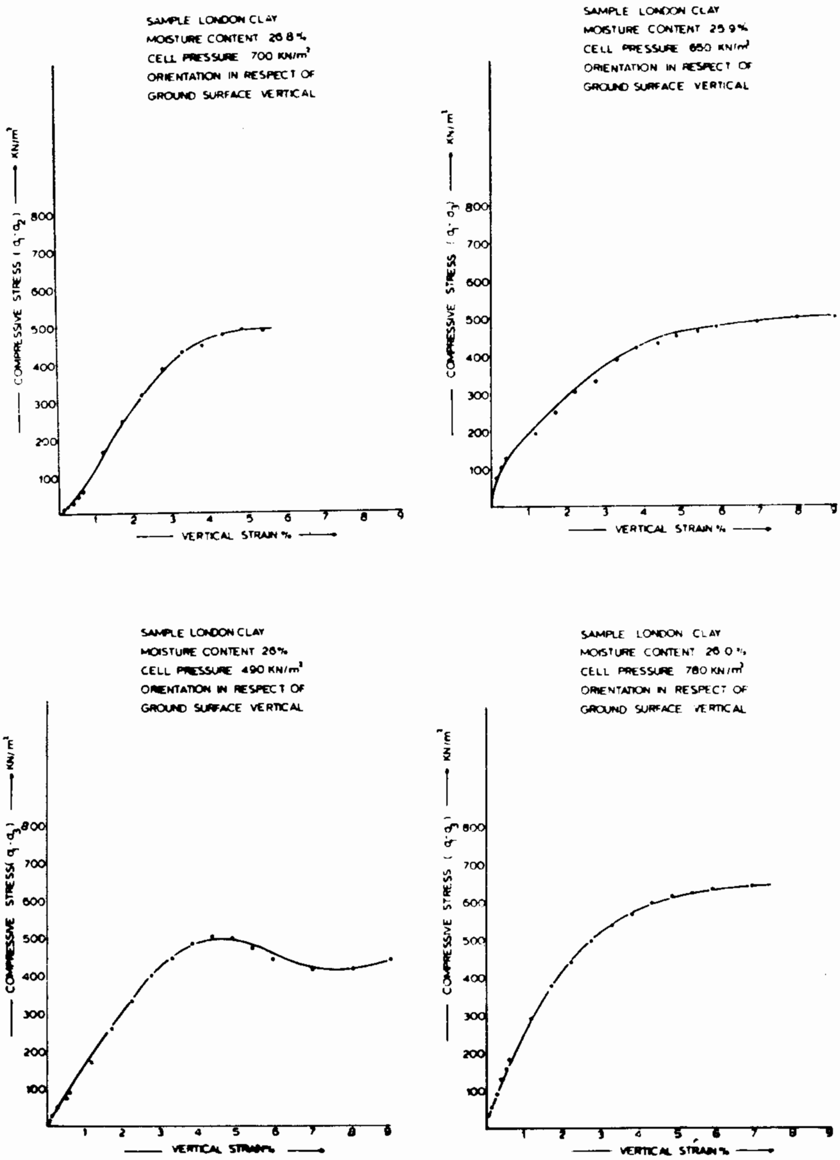
SAMPLE LONDON CLAY
MOISTURE CONTENT 26.8 %
CELL PRESSURE 700 KN/m²
ORIENTATION IN RESPECT OF
GROUND SURFACE VERTICAL
COMPRESSIVE STRESS (σ1-σ3) KN/m²
VERTICAL STRAIN %
SAMPLE LONDON CLAY
MOISTURE CONTENT 25.9 %
CELL PRESSURE 650 KN/m²
ORIENTATION IN RESPECT OF
GROUND SURFACE VERTICAL
COMPRESSIVE STRESS (σ1-σ3) KN/m²
VERTICAL STRAIN %
SAMPLE LONDON CLAY
MOISTURE CONTENT 26%
CELL PRESSURE 490 KN/m²
ORIENTATION IN RESPECT OF
GROUND SURFACE VERTICAL
COMPRESSIVE STRESS (σ1-σ3) KN/m²
VERTICAL STRAIN%
SAMPLE LONDON CLAY
MOISTURE CONTENT 26.0 %
CELL PRESSURE 780 KN/m²
ORIENTATION IN RESPECT OF
GROUND SURFACE VERTICAL
COMPRESSIVE STRESS (σ1-σ3) KN/m²
VERTICAL STRAIN %

Fig. 5.

of the fissures. Another interesting feature is the evidence of the absence of peaks from the stress-strain curves for the vertical group on the contrary with the horizontal group. It was also noticed that the compressive stresses at failure obtained from the stress-strain curves were representably large in the case of horizontal group and relatively small for the vertical group. The stress-strain curves obtained from the above described tests are given in (Figures 4 and 5) for both groups.

Indubitably the existence of fissures in stiff plastic clays are of great importance. Due to this presentation, alteration occurs in the state of stresses and strength of the clay to such a degree which depends on the particular characteristics of the fissures. When an Engineering Geologist is faced with earthworks in slopes or open cuts in fissured clay, he must be very careful; pointing out all the possible factors originated by the fissures which are affecting the whole stability. For any particular geotechnical problem relating to such a clay there is a need for detailed analysis and description of the extent, spacing inclination, orientation and shape of fissures. However, further research is required for various clays in different Geological environments. Particularly the field has demonstrated a need for better understanding of fissures and joints behaviour. Maybe this understanding may lead to creating a more general conclusion and criteria of safety or failure.

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