Short Communications

Electron Microscopic Fabric Studies on some Silt-Clay Matrices

by

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Introduction

Most clay deposits are composite soil aggregates, and the silt-clay matrix concept is more appropriate for the study of the aggregation of silt particles and clay particles within them. Different types of fabrics are encountered in these soils, and they are of a complex nature generally, depending upon the physical properties of the soil involved.

The importance of the structure of soils for consolidation and shear strength behaviour was recognised by Lambe (1958). In more recent times Smart (1969), Sides and Barden (1971), Kirkpatrick and Rennie (1973), Mc Connachie (1974), Collins and Mc Gown (1974) have studied and suggested interaction between various levels of microfabric units. Several reported interaction hypotheses have also been substantial by experimental investigations (e.g. Yong and Sheeran, 1973), but the understanding of the mechanical behaviour of composite soils in terms of their microstructural characteristics is not yet complete.

The paper presents an electron microscopic fabric study related to the consolidation and shear strength behaviour of artificially prepared normally consolidated silt-clay matrices. The silt-clay matrices were constituted of a silt and a clay. Two clays, a kaolinite and an illite, each representative of one main clay mineral group, were used. The studies were done for a range of silt-clay matrices for studying the micro-structural changes in them during consolidation and shear. Various microfabric units, viz., platelets, domains, clusters, peds, clay particle matrix, silt particle matrix and composite micro-aggregates have been studied. An effort has also been made to explain the noted consolidation and shear strength behaviour with the help of a working hypothesis based on the results of the micro-structural studies.

Initial Preparation of Samples

Silt-clay matrices (abbreviated as SCM, henceforth) for kaolinite series and for illite series (indicated by K and I respectively) were formed, by inclusion of clay in the SCM having a percentage varying between the limits 0 and 100, specified exactly by the sample identity, e.g., *K* 65 means

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an SCM having 65 per cent kaolinite and 35 per cent silt in it. Distilled deaired water, in a quantity approximately two times the liquid limit of the constituent clay by weight of SCM, was added to obtain a uniform slurry. The prepared slurry was consolidated under a maximum pressure intensity of 1.5 kg/cm² in a modified C.B.R. mould having the facility of radial drainage and, vertical drainage to yield the 'parent block sample'.

Laboratory Tests

Different percentages of SCM for the *K* and *I* series, covering the full range from 0 to 100, were selected for studying the stress-strain behaviour and pore pressure response from dilatancy considerations.

The several soil samples at the stage of start of the one-dimensional consolidation test were identified as C. 1. Replicate samples of C. 1 were used for microstructural studies. The consolidation tests were performed to a maximum pressure intensity of 4 kg/cm². At the completion of each such test, the soil sample was allowed to rebound in stages to zero pressure (sample identity at the end of this stage was C. 2). Slices, approximately 1.5 cm thick, were cut from the several C. 2 soil samples, and were used for the SEM study after air drying following the method given by Barden, et al. (1971). Relicate C. 2 samples were used for triaxial test. These samples were consolidated in the triaxial cell under effective chamber pressures of 1.7 kg/cm², 2.5 kg/cm² and 3.5 kg/cm². The soil samples obtained in the final stages so achieved were identified as BS. 1. BS. 2 and BS. 3, respectively. Subsequently, the samples were sheared under undrained condition and the corresponding identity of samples was AS. 1, AS. 2 and AS. 3, respectively in the sheared condition.

Evaluation of Microscopic Structure

An ideal study of the microstructures of a clay should involve the three principal different methods, viz., electron microscopy, X-ray diffraction, and optical microscopy. For the same purpose, it has been argued that a specific method may be more suitable for a specific type of microstructural study (Barden, Sides and Polding, 1971). However, thin section polarising microscopy has been used more often perhaps due to the relative simplicity and relatively lesser cost of the equipment involved.

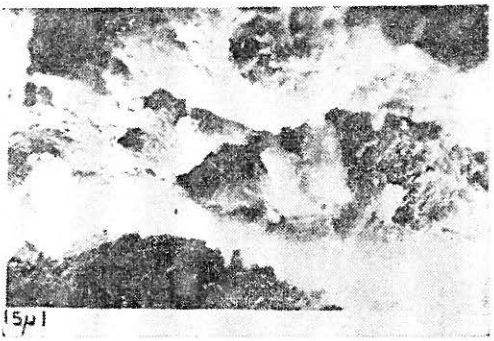
Mc connachie (1974) pointed out that the limitation of optimal microscopy and *X*-ray diffraction is that these methods discern only the orientation of fabric, extending over areas containing a large number of microfabric elements. Electron microscopy was therefore the chosen method for these studies. The identification of the different component elements of microstructure in silt-clay matrices was done following the usual methods and definitions given in the literature (e.g., Collins and Mc Gown, 1974).

In this paper, only a few of the chosen representative electron micrographs have been included. For a comprehensive coverage, the reader is referred to Sadana (1978).

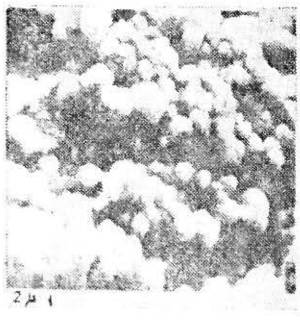
Photograph 1 shows the microstructure for *KO*/C.2 (Silt consolidated to a pressure intensity of (4 kg/cm²). It is seen from this photograph that silt particles varying in size from 2 microns to about 40 microns in diameter are in contact with each other in general, and they are irregular in shape and arrangement within the matrix, occurlng in the form of irregular aggregations. Most of the pores observed may be classified intra-elemental pores, and these pores are of varying dimensions (2 microns to 35 microns). The void ratio exhibited by silts is mainly due to these pores.

Photographs 2 to 6 show the microstructure corresponding to *K* 24/*C*.2 *I* 65/*C*.2, *K* 24/*AS*. 3, *I* 30/*AS*.2 and *K* 100/*AS*. 3. Single particle

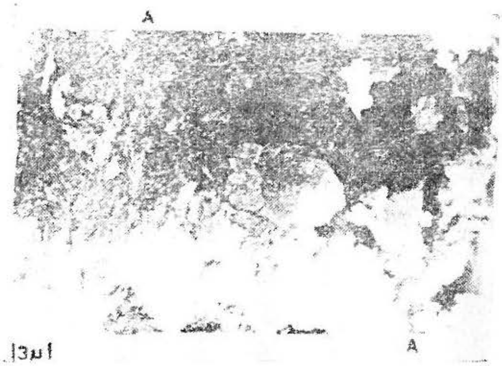
PHOTOGRAPH 1 Micrograph of OSCM (silt) for Condition C. 2.



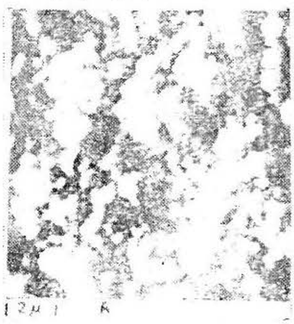
PHOTOGRAPH 2 Micrograph of 24 SCM (Krolimite) for condition C. 2



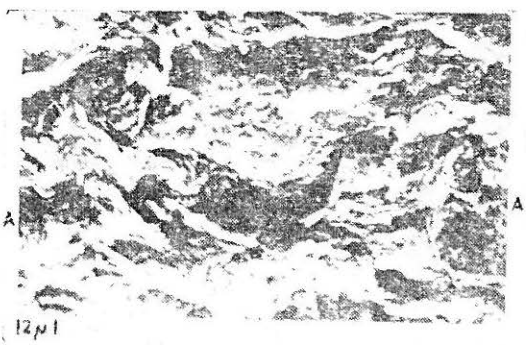
PHOTOGRAPH 3 Micrograph of 6.5 SCM (Illite) for condition C. 2.



PHOTOGRAPH 4 Micrograph of 24 SCM (Kaolinite) for condition AS. 3



PHOTOGRAPH 5 Micrograph of 30 SCM (Illite) for condition AS. 2



PHOTOGRAPH 6 Micrograph of 100 SCM (Kaolinite) for condition AS. 3

interaction, as noted on Photograph 1 for silt, is no longer apparent on these photographs. This is in conformity with the observation of Smart (1971) that single particle interaction is extremely rare in silt-clay soils. These micrographs also show clearly the tendency for the clay particles to form aggregations. The edge-edge and edge-face interaction of clay platelets, and the geometry of interassemblage pores are easily distinguishable in all the photographs mentioned above.

Photographs 2 to 5 corresponding to *K* 24/*C*.2, *I* 65/*C*.2, *K* 24/*AS*.3 and *I* 30/*AS*.2 respectively, also show that the silt particles are clothed in peels of clay particles and clusters. It is also apparent that silt particle clothing is such that peels are not fully developed all round the silt grains, and they cover the silt grain surface only partially. The clay particles form aggregations which are linked by chains (connectors) of fine clay plates, as distinguished first by Pusch (1973). The aggregations formed are observed to be interacting with the clay particle matrix. Intra-assemblage and inter-assemblage pores are seen to be pronounced in these photographs.

In the photographs 4, 5 and 6 corresponding to K 24/AS.3, I 30/AS.2 and K 100/AS.3 respectively, the direction AA indicated thereon, most probably represents the direction of the shear plane. They also show that the SCM microfabric units have a tendency to orient in the direction of the shear plane.

Microstructural Hypothesis

Based on the observations and analyses of the micrographs presented above, a microstructural hypothesis for explaining the observed consolldation and triaxial behaviour of SCM is presented in this section.

Depending on the percentage of clay present in the SCM, the disposition of silt grains is considered to be either 'enmeshed' or 'flating' in the background matrix of clay. The silt particles are relatively free to come in contact with each other in O SCM, and the behaviour of the soil is therefore governed by granulometric properties of the matrix. With the increase of percentage of clay in SCM, domains and clusters tend to develop and surround the silt particles to form peels of different orders of development. At lower clay contents in SCM, the interaction of domains and clusters may give rise to microfabric units in which the clay peels are not fully formed around the silt particle, and the clay units cover the silt particles surface only partially.

With further increase in clay content, the silt particles get 'enmeshed' in peels of clay particle matrix comprised of platelets, domains, clusters and peds, occurring singly or severally in different combinations. At this stage the peels are fully developed and enmesh the entire surface of the silt grain. With still larger increase in clay content, the composite micro-aggregates and silt particles no longer experience the restraints of the enmeshed condition, and become free to occupy whatever 'zero energy' or equilibrium positions are available. This condition is appropriately the one corresponding to the silt grains 'floating' in the matrix of clay.

Engineering Behaviour

Consolidation and shear behaviour of the SCM have been explained with the help of the microstructural hypothesis in the section.

Consolidation Behaviour

The behaviour of O SCM is controlled by the granulometric properties of the matrix. The consolidation loading is transmitted at the contact points of silt particles, as the soil skeleton is already well developed in O

SCM. Thus, in the elastic range, the soil structure does not undergo any appreciable change either in its geometry or in its size.

With increased percentage of clay in SCM, clay domains and clusters interact with silt particles, and composite microaggregates tend to form. In a composite micro aggregate, the silt grain is partially or completely enmeshed in clay particle matrix, and at this stage the behaviour of SCM is controlled by such microfabric units. With further increase of clay content in SCM, the composite microaggregates tend to float in the background matrix of clay particles exhibiting clayey behaviour.

Shear Behaviour

In the initial stages of the application of deviator stress, the stress is transmittted at the contact points of granular particles. With the increase of shearing stress beyond the elastic limit, there is a breakege of some contact points and the deformation of soil skeleton occurs, resulting in change of volume. If the soil is dilatant, this change in volume is positive, with the attendent drop in pore pressure.

with the increase of clay content in SCM, the development of 'composite microaggregates' takes place. Each composite microaggregate comprising of a core of a silt grain and an 'onion type' peel of clay domains and clusters, is capable of altering or restricting the free development and alignment of failure planes. Occasionally the whole of such composite microaggregates are sheared offthrough the background matrix of clay particles, depending on the intensity and direction of shear stress being transmitted through it. This may cause dilatancy and a drop in pore pressures.

If the clay content in the SCM is increased further, it helps the composite microaggregates to float in the background matrix of clay as a result of which they do not get sheared off during deviator stress application, but get reoriented without causing any change in volume. The pore pressure therefore naturally gets stabilised at this stage.

Conclusions

In the study of microstructures of silt-clay matrices, the smaller microfabric units, viz., platelets, domains, clusters, and the larger microfabric units, viz., composite microaggregates are easily observable in the scanning electron microscope. Elementary particle arrangements and particle assembleges together with pore spaces are considered most pertinent microfabric features. The microstructural hypothesis evolved, as a result of the observation and analysis of the microstructures of the silt-clay matrices, and based essentially on the 'enmeshed, and 'floating' condition of the silt grain of the silt-clay matrix explains the consolidation and shear behaviour of silt-clay matrices satisfactorily.

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