swelling pressures to be expected in the field for the soil investigated. It is speculated that the reduction of swell due to the mobilization of frictional stresses in a one-dimensional oedometer is equivalent to a reduction in soil heave in the field due to radial expansion (axisymmetric swelling).

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Role of Mineralogical Composition in the Activity of Expansive Soils

MOHAMED A. EL SOHBY, SAYYED A. RABBA, and OSSAMA MAZEN

ABSTRACT

Heave-susceptible soils often contain swelling clay minerals. Knowledge of the mineralogy of soils and rocks plays a large part in understanding the mechanical behavior of these materials. This knowledge is used to the best advantage when it is combined with information about the engineering properties and geological history of the deposits. The object of this paper is to use the knowledge of microstructure and composition of expansive clayey soils to evaluate the activity as defined by various researchers. Therefore, different kinds of clayey soils were investigated for their index properties, activities, and mineralogical compositions. Samples for study were taken from Madinet Nasr, an area in the suburbs of Cairo where expansive soil deposits predominate. The activities of soil samples were determined by using formulae proposed by different researchers. The values of activities were then correlated to the mineralogical compositions of tested soils. The study indicated that the activity is a property of clay mineral rather than a property of whole sample and confirmed the effect of nonclay mineral or coarse-grained fraction on activity values of expansive soil deposits.

MINERALOGY OF EXPANSIVE SOILS

Expansive clays and clay bed rock formations are made up of several mineral constituents. In Egypt the responsible clay minerals are generally detrital and have been inherited from older rocks. Elsewhere swelling clay minerals have formed by in situ weathering of parent rocks as, for example, in South Africa. The amount of potential volume change is dependent on the mineralogical composition: clay mineral type, clay mineral content, and exchangeable ion.

Kerr has indicated that approximately 15 minerals are ordinarily classed as clay minerals (1). These minerals possess in common an extraordinary ability to attract to their surface dipolar water molecules and various cations. Lambe and Whiteman found that swellability varies with the type of clay mineral; it decreases in the order montmorillonite, illite, attapulgite, and kaolinite (2). Mitchel found that most expansive soils contain montmorillonite and vermiculite (3).

Many investigators studied the effect of the amount of clay on swelling (3-7) and agreed that the amount of swell and swelling pressure increases with the increase of clay content.

The effect of exchangeable ion on swellability was also studied by various researchers whose work many be summarized as follows (2,8-11). For soils containing expansive clay minerals, the type of exchangeable ion exerts a controlling influence over the amount of expansion that takes place in the presence of water. Therefore, researchers are in complete agreement in considering the mineralogical identification as the primary method for classifying potentially expansive soils. The techniques for mineralogical identification vary. They include microscopic examination, x-ray diffraction, differential thermal analysis, dye adsorption, and chemical analysis.

ACTIVITY OF EXPANSIVE SOILS

Tests for mineralogical identification are generally elaborate; the specialized apparatus required are costly, and test results require expert interpretation. Therefore, a substantial amount of research has been conducted to replace the mineralogical identification with indirect methods for the evaluation of swelling potential of expansive soils. This could be achieved by using some simple soil property tests as primarily indicators of the presence of expansive clay minerals. Such tests may include Atterberg limits, free swell, and colloid content.

The activity method of evaluating the swelling potential of expansive soils appears to be an improvement over the preceding indicators in that the effect of both plasticity index and clay content enter in the identification of different clay minerals and the indirect evaluation of swelling potential.

Measurement of Activity

Skempton defined the activity as the ratio of the plasticity index to the abundance of clay content expressed as the percent dry weight of the minus 2 micron fraction of the sample (4). Therefore the activity $A = PI/C$, where PI is the plasticity index and C is the clay content.

Seed, Woodward, and Lundgren conducted further studies on a large number of artificially prepared sand clay mineral mixtures (12-14). They found that the line representing the relationship between the plasticity index and percent clay size does not always pass through the origin. It may intersect the percent clay size axis at values as high as 10 percent. Thus they introduced a modification to Skempton's definition in the form of $A = PI/C\text{-}n$, where n is approximately equal to 5 for natural soils and equal to 10 for artificial soils.

El Sohby, while studying a large number of samples with different contents of clay, silt, and sand (7), noted the same observations made by Seed et al. However, he found that the PI-C relationship may intersect either the PI-axis or the C-axis according to the grain fraction coarser than 2 micron in the soil sample. Thus the deviation from the origin of the straight line representing the PI-C relationship was attributed to the effect of coarse-grained fraction.

To incorporate the effect of coarse-grained fraction, El Sohby presented a new modification of the definition of activity as follows:

$$A = PI\ (100 \pm n)/100\ (C \pm n)$$

where n is the intercept of the clay percent axis.

CURRENT STUDY

The aim of this study is to analyze the factors that affect activity values and to evaluate the different methods for their measurement in the light of the mineralogical composition.

Therefore, a number of clayey soil samples representing different mineralogical compositions were investigated. First, the activities of the clayey soil samples were determined according to each of the previously mentioned three formulas. Then these activities were correlated to the mineralogical compositions as determined by the use of x-ray diffraction analysis.

Test Program

The investigation was carried out on 11 clayey soil samples selected from different locations and depths in Madinet Nasr, an arid, newly developed area located 8 km north-east of Cairo. Expansive clayey soils were found to occur with a relatively high frequency in this area.

Specimen Preparation

Two groups of specimens were tested during the investigation: (a) specimens of samples in their natural state and (b) prepared specimens consisting entirely of clay fraction (particles less than 2 micron). The second group was obtained by separation after deposition in distilled water of the clay fraction from soils of the first group.

Testing

The two groups of soil specimens were tested for the following properties (see Table 1 and Figure 1):

1. Mineralogical composition,
2. Atterberg limits for whole sample,
3. Atterberg limits for particles less than 2 micron, and
4. Grain size distribution and clay content.

TEST RESULTS AND ANALYSIS

Activity and Clay Mineral Type

Various researchers have correlated the activities with the type of clay mineral (2-4,15). In this study, the mineralogical types of tested soils were correlated with their activities as determined by each of the three formulas given by Skempton, El Sohby, and Seed et al. (4,7,13) (Table 2).

Comparing the mineralogical composition of each sample with its activity as determined from each of the previously mentioned formulas, it was found that the formula proposed by El Sohby is the only one that can provide a good correlation between type of clay mineral and activity.

For example, Soils G1, C, and G3 have identical mineralogical compositions (Table 2). Their activities, when estimated according to the El Sohby formula, are 0.78, 0.80, and 0.84, respectively. However, their activity values become 0.0, 0.93, and 0.73, respectively, when estimated according to Skempton, and 0.0, 0.79, and 1.07 when estimated

TABLE 1 Summary of Mineralogical Composition of Tested Soils

Sample Number	Clay content (particles less than 2 micron)	Clay mineral	Non-clay mineral	
			Sili-cate	Salt & metal minerals
B	20%	Sodium (M-V) 20%	25%	55%
G3	62%	Calcium (M-V) 62%	16%	22%
G1	46%	Calcium (M-V) 46%	25%	29%
A	59%	Calcium (M-V) 42% + Kaolinite 17%	24%	17%
C	6%	Calcium (M-V) 6%	31%	63%
G2	44%	Potassium (M-V) 44%	26%	30%
E	50%	Potassium (M-V) 39% + Kaolinite 11%	34%	16%
F	5%	Potassium (M-V) 5%		
H2	48%	Potassium (M-I) 41% + Kaolinite 4% + Illite 3%	26%	26%
H1	34%	Potassium (M-I) 26% + Kaolinite 3% + Illite 6%	26%	30%

(M-V): Montmorillonite - Vermiculite

(M-I): Montmorillonite - Illite

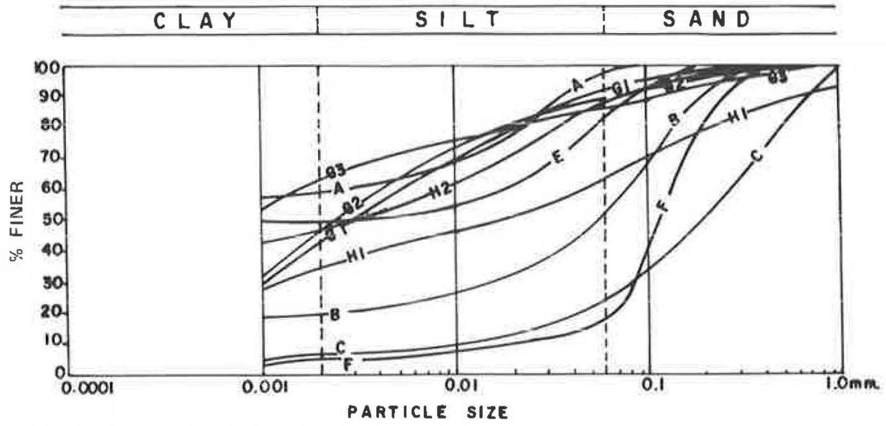

FIGURE 1 Grain size distribution curves of tested samples.

according to Seed et al. Also, the mineralogical composition of Soils F and G2 is the same, but their activity values are only similar if calculated on the basis of the El Sohby formula--they are 0.73 and 0.71, respectively. On the other hand, these values are 0.0 and 0.89 when determined by the Skempton formula, and 0.0 and 1.0 when determined using Seed et al. (Table 2).

Furthermore, a good interpretation of results could be achieved when the El Sohby formula was used. For example, Soils G1, C, and G3 consist of 100 percent calcium (montmorillonite-vermiculite); their average activity is 0.81. Soil A consists of 71 percent calcium (montmorillonite-vermiculite) plus 29 percent kaolinite; its value of activity is 0.75. Also, Soil F consists of 100 percent potassium (montmorillonite-vermiculite), and its value of activity is 0.73. When, in Soil E, the 21 percent

TABLE 2 Clay Mineralogy and Activity of Tested Soils

Soil No.	Mineralogical Composition	Clay Content "C" %< 2um	Plast. Index "PI"	PI of Part <2um	Activity "A"		
					Skempton (1953)	Seed et al (1962)	El Sohby (1981)
B	Sodium (Mont-Verm)	20	16	153	0.80	1.07	1.53
G3 C G1	Calcium (Mont-Verm)	62 6 46	45 0 43	84 80 78	0.73 0 0.93	0.79 0 1.05	0.84 0.80 0.78
F G2	Potassium (Mont-Verm)	5 44	0 39	73 71	0 0.89	0 1.0	0.73 0.71
A	Calcium (Mont-Verm) 71% + Kaolinite 29%	59	54	75	0.90	1.0	0.75
E	Potassium (Mont-Verm) 79% + Kaolinite 21%	50	36	57	0.72	0.80	0.57
H1	Potassium (M-I) 75% +Illite 16% +Kaolinite 9%	34	43	60	1.26	1.48	0.60
H2	Potassium (M-I) 85% +Illite 7% +Kaolinite 8%	48	39	70	0.81	0.91	0.70
D	-	13	24	76	1.86	3.0	0.76

kaolinite existed in addition to the 79 percent potassium (montmorillonite-vermiculite), the activity was reduced to 0.57 (Table 3).

Activity and Exchangeable ion

Researchers appear to be in complete agreement with the contention that ion hydration plays a large part in water uptake by clay mineral (2-4,8,9).

Skempton stated that the activity of sodium montmorillonite is about five times greater than the activity of calcium montmorillonite (4). Lambe and Whiteman found that swellability depends considerably on the exchangeable ion, but not in the same way with each mineral; lithium (Li^+) and sodium (Na^+) clays are the more expansive from (2). Rosenqvist indicated that lithium and sodium montmorillonites have abnormally high power because their cations cannot keep the single sheets of the lattice together (8). In the larger alkali ions, namely potassium, the internal swelling property is absent. Gillot stated that calcium montmorillonite commonly takes up only two layers of water, whereas sodium montmorillonite imbibes more water, in variable amounts.

This was only confirmed in this study when the El Sohby formula was used for activity values of tested soils (Table 4). For example, Soils B, G1, C, G3, F, and G2 are mixed layers of montmorillonite-vermiculite, but the exchangeable ion varies. It was found that the results of activities vary with the variation of the cation as cited in the literature. The activity of 1.53 of Soil B with sodium as the cation is the highest value compared with 0.78, 0.8, and 0.84 for Soils G1, C, and G3 with calcium as the cation, and 0.73 and 0.71 for Soils F and G2 with potassium as the cation.

On the other hand, when the values of activity were obtained using Skempton's formula or the modified Seed et al. formula, the effect of exchangeable ion on the value of activity could not be verified. As indicated in Table 2, the activity of Soil B with sodium as the cation is less or almost the same as the activity of Soil G1 with calcium as the cation. Also, the activity of Soil C with calcium as the cation is zero, whereas the activity of Soil G2 with potassium as the cation is 0.89 and 1.0.

Activity and Non-Clay Mineral

Because the plasticity index reflects the capability of a certain soil to absorb water, which, in turn, is affected by the surface area of soil particles, it may be expected that silts need a smaller amount of clay than sands to develop plasticity.

TABLE 3 Effect of Presence of Kaolinite on Activity of Tested Soils

Mineralogical composition	Calcium (Mont-Verm) 100%			Calcium (Mont-Verm) 71% + Kaolinite 29%	Potassium (Mont-Verm) 100%	Potassium (Mont-Verm) 79% + Kaolinite 21%
Soil sample	G1	C	G3	A	F	E
Activity	0.78 (average 0.81)	0.8	0.84	0.74	0.73	0.57

Mont.: Montmorillonite

Verm.: Vermiculite

TABLE 4 Activity and Exchangeable Ions

Type of clay mineral	(Montmorillonite - Vermiculite) mixed layers					
Type of Exchangeable cation	Sodium Na^+	Calcium (Ca^{++})			Potassium K^+	
Activity	1.53	0.78	0.80	0.84	0.73	0.71
Average value	1.53	0.81			0.72	
Soil No.	B	G1	C	G3	F	G2

El Sohby, by studying a large number of prepared soils consisting of different percentages of clay, silt, and sand, noticed that a straight line representing the PI-C relationship may intersect the clay content percent axis at either a positive or a negative value depending on the type of the non-clay mineral (coarse-grained fraction) in the soil (7).

It is observed in this study that the lines representing the PI-C relationship intersect the C-axis at points of ±n (see Figure 2). It is noted that for soils with relatively high percentages of sand (Figure 3), these lines intersect the C-axis at points of +n, whereas for soils with relatively low percentages of sand the lines intersect the C-axis at points of -n (see Figure 4).

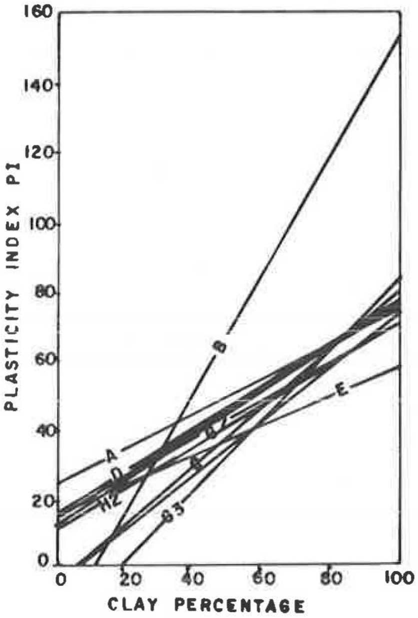

FIGURE 2 Relationship between plasticity index and clay percentage.

Figure 5 shows the relationships between plasticity index of clay mineral and clay content for idealized soils of different mineralogical composition. In this case these relationships are represented by straight lines passing by the origin. The slope of each line represents the activity of the clay mineral.

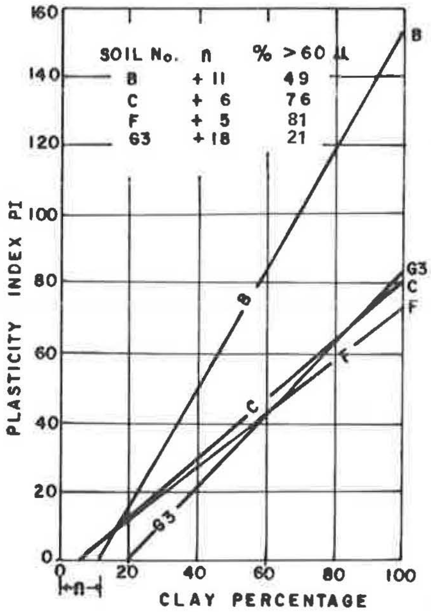

FIGURE 3 Influence of coarse-grained fraction on the relationship between plasticity index and clay percentage (soils of relatively high percentage sand).

CONCLUSIONS

From the foregoing study of the mineralogical composition of clayey soil deposits and their relationships to their activity values as measured using formulas given by different investigators, the following conclusions may be drawn.

1. The role of mineralogical composition of expansive soils (clay minerals and non-clay minerals) in the values of activity is evidenced and available knowledge is confirmed.
2. There are two criteria for activity values of clayey soils: (a) activity values of the 100 percent clay content soils and (b) activity values of natural soils.
3. The formula proposed by Skempton is directly related to the 100 percent clay content soils (4). The blind use of this formula could yield unreliable activity values.
4. For natural soils, the incorporation of the coarse-grained fraction (as an important parameter) in the determination of activity is an essential

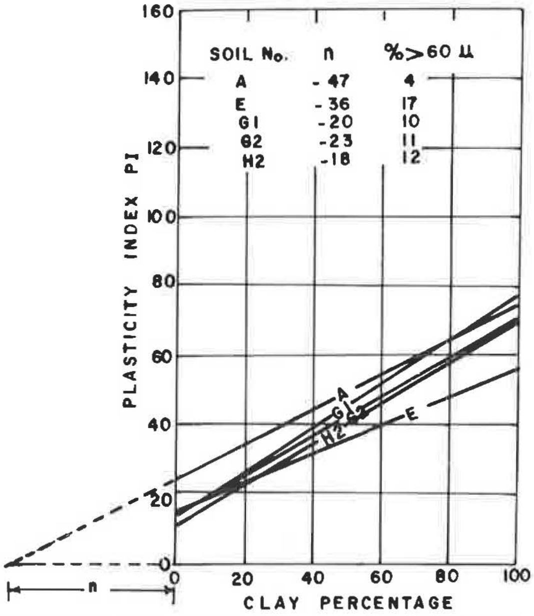

FIGURE 4 Influence of coarse-grained fraction on the relationship between plasticity index and clay percentage.

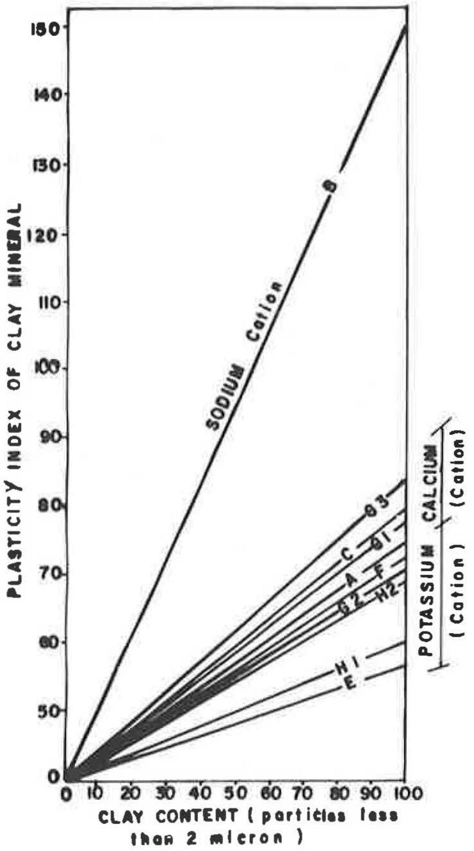

FIGURE 5 Relationship between plasticity index of clay mineral (particles < 2 um) and clay content (idealized soil).

prerequisite to developing accurate values. In this study, this could only be achieved when the formula proposed by El Sohby was used (7).

5. It is suggested that charts based on activity for the determination of potential expansiveness of clayey soils be reevaluated with the effect of coarse-grained fraction parameter considered (4,15-17).

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