THE MECHANICAL PROPERTIES OF SIMULATED SOIL-ROCK MIXTURES

LES PROPRIETES MECANIQUES DE MELANGES TERRE-PIERRE SIMULES

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SYNOPSIS: Materials forming part of rockfill dams, debris flows and residual soils are made of a mixture of large rock particles embedded in a matrix of clayey soil. This study presents consolidation, permeability and shear strength tests designed to understand the influence of the granular and soil phases on these properties. From testing mixtures of kaolinite clay with glass beads or sand, it was found that the percentage of the granular phase in the mixtures has a marked influence on the compression index, coefficient of permeability and shear strength of the mixtures. From direct shear tests on mixtures of kaolinite clay and Ottawa sand it was found that when the sand concentration volume was between 80 and 100%, the shear strength of the sand controlled the strength of the mixtures. When the sand concentration was between 80 and 50%, the shear strength of the mixtures was provided in part by frictional resistance between the sand and in part by the shear strength of the clay. If the sand concentration was less than 50%, the shear strength of the mixtures was governed entirely by the shear strength of the clay.

INTRODUCTION

Materials forming part of rock fill dams, glacial tills, mudflows, debris flows, solifluction sheets and residual soil deposits have a distinct structure, this consisting of a mixture of large particles (gravel or hard clay fragments) and a soft matrix of soil (clay, sand or sand-silt-clay mixture) (Vallejo, 1989; Zhou, 1989). To analyze the consolidation and stability characteristics of soil structures made of this type of mixture, their compression characteristics, permeability and shear strength are needed. These mechanical properties will depend upon the relative concentrations of the large particles and the soil matrix as well as the interactions between these two components in the mixture.

Very few laboratory investigations involving the determination of the consolidation characteristics, the permeability, and the shear strength of soil-rock mixtures have been conducted to date. The reason for this is that the determination of such mechanical properties requires the use of large chambers that can accomodate the large particles in the mixture and the use of large loading sytems that can simulate field stress conditions. Recently, Fragaszy, et al. (1990, 1991) have conducted laboratory tests on large samples of sand-gravel mixtures in order to evaluate their density and shear strength. Clay-rock mixtures, however, have received little attention.

In order to better understand the behavior of clay-rock mixtures in the field, the present study reports the results of a laboratory investigation that used conventional laboratory equipment and simulated soil-rock mixtures. The compression index, the coefficient of permeability, and the shear strength were measured on a mixture of kaolinite clay (representing the soil component in the mixture) and glass beads of different sizes or sand (representing the granular component in the mixture).

MATERIALS USED FOR EXPERIMENTS

The simulated soil-rock mixtures were developed in the laboratory by mixing kaolinite clay with glass beads or Ottawa sand. The kaolinite clay had a liquid limit of 58% and a plastic limit of 28%. Its specific gravity was equal to 2.65. The kaolinite clay represented the soil phase in the mixtures. To simulate the granular phase in the soil-rock mixtures, glass beads of two different diameters (12.7 mm and 5 mm) and Ottawa sand with an average diameter of 0.8 mm were used in the experiments. The glass beads as well as the Ottawa sand had specific gravities equal to 2.67. The glass beads were used for both the consolidation and the permeability experiments; the Ottawa sand for the shear strength experiments.

CONSOLIDATION CHARACTERISTICS

Compression Index, C_c

Consolidation tests were conducted on simulated soil-rock mixtures represented by kaolinite clay plus glass beads . The glass beads had diameters of 12.7 and 5 mm.

To prepare the samples for the consolidation tests, first dried kaolinite clay was mixed with distilled water to form a paste with a water content of about 50%. This paste was then placed into a consolidometer 30 cm in diameter and 7.6 cm in height. This sample was then consolidated under a normal pressure of 47.9 kPa for two days. The purpose of this pre-compression was to remove entrapped air bubbles which formed during the process of placing the paste into the consolidometer. At the end of the two days of consolidation, the water content of the clay paste was equal to 40%. This paste from the 30 cm consolidometer was then used to run standard consolidation tests (samples with diameter = 6.35 cm and height = 2.54 cm) on mixtures of clay plus glass beads as well as on clay alone. The glass beads were placed in layers in the clay that filled the consolidation ring (Fig. 1). The amount of glass beads in the samples was measured using their volume concentration ratio B (ratio of volume of glass beads and volume of glass beads plus clay).

After the clay or the clay-glass beads mixtures were placed in the consolidation ring, they were subjected under saturation conditions, to 24 hour duration incremental loads equal to 399, 798, 1596, 3192, 6384, and 12768 kN. From these tests, relationships betweeen the void ratio, e, and the log. of effective pressure, p', were obtained. From the e versus log. p' relationships, the value of the Compression Index, C_c , was determined. The value of the compression index is given by the slope of the e versus log.p' lines. Fig. 1 shows a plot of the values of C_c for four consolidation tests run on clay only and on mixtures of clay and the 12.7 mm glass beads placed in one layer in the ring. An analysis of Fig. 1 indicates that the C_c for the samples made of clay only changed very little and had a C_c value of about 0.25 . For the clay-glass beads mixture, the value of C_c decreased as the percentage of glass beads in the mixture (given by volume concentration ratio B) increased. Results similar as those shown in Fig. 1 were obtained for the samples containing the 5 mm glass beads.

Next, the C_c values for all the clay-glass beads mixtures were normalized with respect to the C_c value of the tests in clay only. Plots of the ratio of these two compression indexes (called the normalized compression index) versus the volume concentration ratio, B , of the glass beads in the mixtures are shown in Fig. 2.

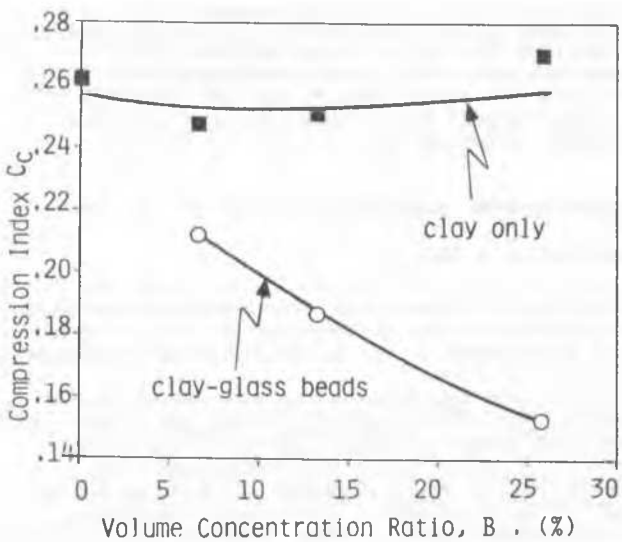

Fig. 1 Compression Index of mixtures.

Naming the compression index for the clay-glass beads mixtures, C_c , and the compression index for the clay only, C_{cc} , the best relationship that describes a ratio of these two compression indexes has been obtained by Zhou (1989) and is given by the following equation:

$$\frac{C_c}{C_{cc}} = \left(\frac{(1-B)}{(1+eB)}\right) \quad (1)$$

where e is the void ratio of the clay where the glass beads are embedded. Using the measured constant void ratio e for the clay matrix (e = 1.207), a plot of of the normalized compression index (Eq. 1) as a function of different values of the glass beads volume concentration ratio, B , is shown in Fig.2. A good match was obtained between the laboratory results and the values obtained from Eq. 1.

From an analysis of Figs.1 and 2 and Eq.1, it can be concluded that the compression index of the simulated rock-soil mixtures given by C_c can be obtained from the values of the compression index of the soil matrix C_{cc} , its void ratio e , and the volume concentration ratio B of the granular phase.

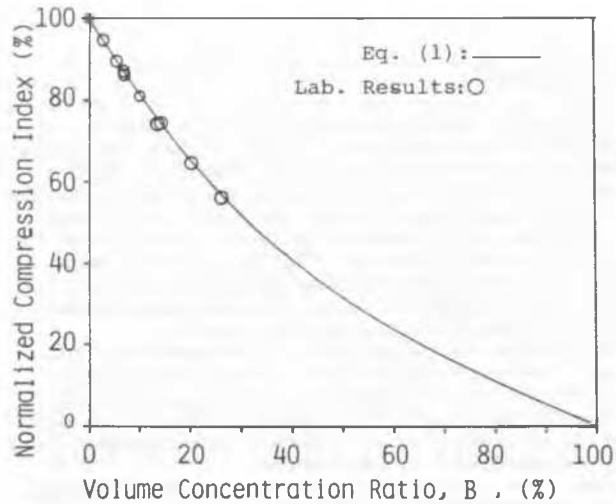

Fig. 2 Normalized Compression Index of mixtures

PERMEABILITY CHARACTERISTICS

For the permeability studies of simulated soil-rock mixtures, samples of clay plus glas beads as well as clay alone were prepared using a Harvard miniature compaction mold. The clay for the samples was obtained from the clay paste prepared in the large consolidometer 30 cm in diameter. The glass beads used in the mixture had diameters equal to 12.7 and 5mm in diameter. The glass beads were placed in layers in the clay filling the Harvard miniature mold and were compacted using a kneading process. After the samples were prepared in the Harvard miniature mold, they were removed and placed in a cylindrical cell. In this cell that forms part of a constant head permeability testing apparatus, the samples were subjected to two confining pressures equal to 379 and 483 kPa. After the confinement pressures were in effect water was allowed to permeate through the samples under a constant head pressure of 172 kPa. Using the amount of water discharged from the clay or clay-glass beads mixtures as well as the dimensions of the samples tested, the coefficient of permeability of the clay-glass beads mixtures, k, and of the samples made of clay alone, k_c, were determined. Fig. 3 shows a plot of the measured coefficients of permeability versus the glass beads volume concentration ratio, B. An analysis of Fig. 3 indicates that as the amount of glass beads increased in the samples, the coefficient of permeability decreased.

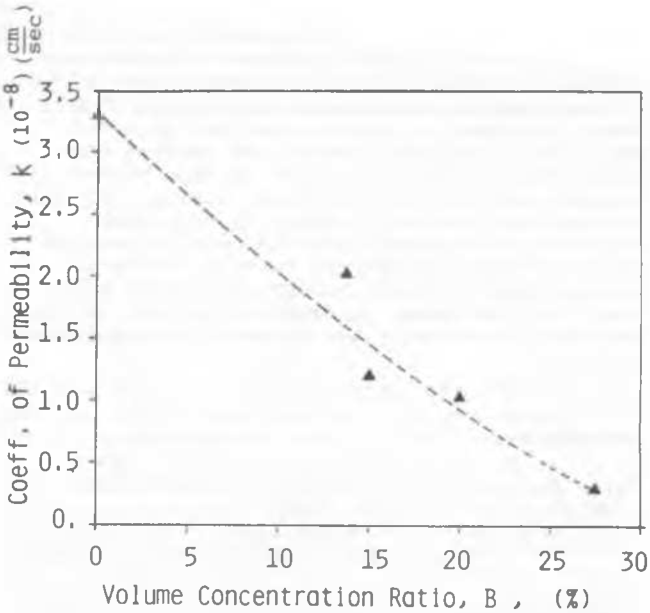

Fig. 3 Coefficient of permeability of mixtures.

Next the k values for all the clay-glass beads mixtures were normalized with respect to the k_c value obtained on the samples of clay alone. Plots of the ratio of these two coefficients of permeability (called the normalized coefficient of permeability) versus the volume concentration ratio, B, of the glass beads in the mixtures is shown in Fig. 4.

Zhou (1989) has shown that a relationship that best describes the ratio of k and k_c can be obtained from the following equation:

$$\frac{k}{k_c} = \frac{(1-B)^3}{(1+eB)^2} \qquad (2)$$

where e is the void ratio of the clay where the glass beads are embedded. Using the measured value of e for the clay equal to 1.207, a plot of the normalized coefficient of permeability (Eq. 2) as a function of different values of the glass beads concentration ratio, B, is shown in

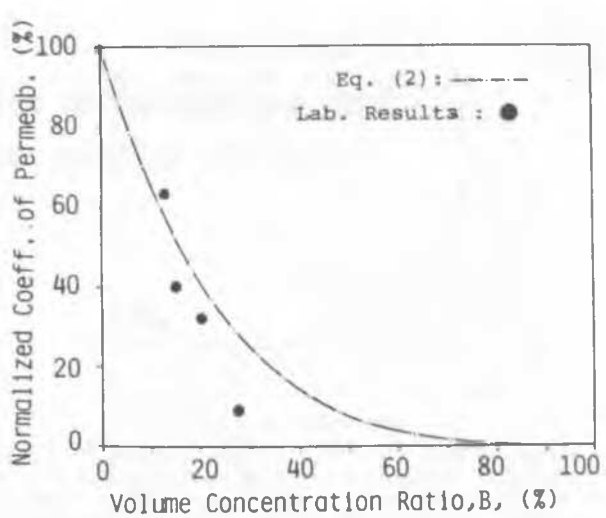

Fig. 4 Normalized coefficient of permeability for the mixtures.

Fig. 4. A good match was obtained between the laboratory results and the values obtained from Eq. 2.

From an analysis of Fig. 4 it can be concluded that the coefficient of permeability of the simulated soil-rock mixtures, k, can be obtained if one knows the coefficient of permeability of the soil matrix, k_c, its void ratio, e, and the volume concentration ratio B of the granular phase.

SHEAR STRENGTH

For the shear strength experiments on simulated soil-rock mixtures, kaolinite clay and Ottawa sand were used. The clay and the sand were mixed and placed in a standard direct shear box measuring 60x60 mm. The water content of the samples was maintained at 31.7 %. Three normal pressures were used in the shearing experiments. These were equal to 54.26, 102.17, and 150 kPa. The samples tested had sand volume concentration ratios, B, equal to 0, 15, 26.1, 61.4, and 100%.

The average diameter of the Ottawa sand was equal to 0.8 mm. According to Lewis (1956), the maximum diameter of granular particles that can be used in a standard direct shear box is equal to 1 mm. If particles larger than 1 mm are used, the shear strength determined from the tests will be erroneous. For this reason, Ottawa sand that measured 0.8 mm in diameter was used instead of the 12.7 and 5 mm glass beads.

From the direct shear tests on samples of clay, sand, and clay-sand mixtures plots such as the one shown in Fig. 5 were obtained. This figure shows a curve A and a line B. Curve A connects points representing the maximum shear strength measured in clay-sand mixtures as determined in the direct shear apparatus. Line B represents the contribution by the sand to the shear strength measured in the clay-sand mixtures. This line B was obtained by connecting the values of shear strength of sand when its concentration by volume in the samples was 100% and 0%. The shear strength of the sand clay-mixtures (Curve A) was determined under a normal pressure equal to 150 kPa.

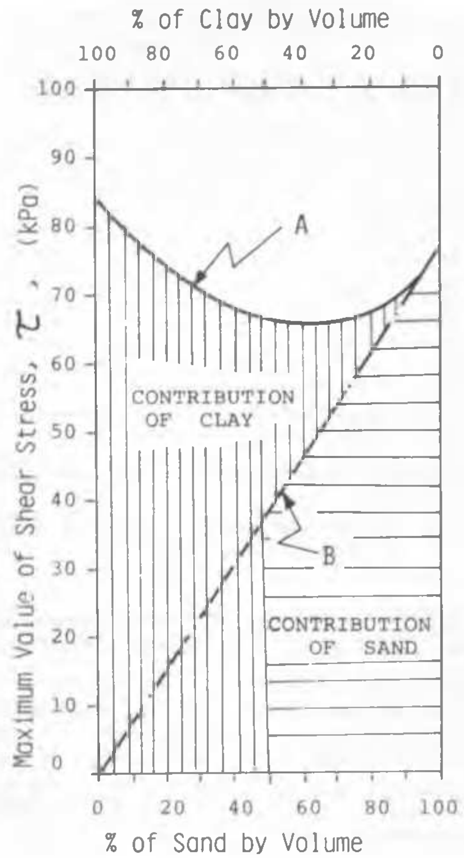

Fig. 5 Results from direct shear tests on mixtures under a σ_n = 150 kPa.

An analysis of Fig. 5 indicates that for sand concentrations between 100 and 80% in the clay-sand mixture, its shear strength is provided almost entirely by the sand in the mixtures. When the sand concentration by volume in the mixtures varied between 80 and about 50%, the shear strength of the mixtures was provided in part by the shear strength of the clay and in part by the frictional strength between the sand grains. According to Harr (1962), the loosest possible packing of uniform spheres occurs when their volume concentration is equal to 52.4%. At this volume concentration the spheres will be barely in contact and friction will start to develop. Thus, a lower limit of 50% at which the sand contributes to the strength of the sand clay mixtures seems a reasonably one. When sand concentration volumes range between 50% and 0%, the shear strength of the mixtures is dictated entirely by the clay matrix.

CONCLUSIONS

From consolidation, permeability, and shear strength tests on mixtures of clay and glass beads and clay and sand, the following were established:

(1) The amount of glass beads or sand in the mixtures had a tremendous influence on the values of the compression index, coefficient of permeability and the shear strength measured on the mixtures. It was found that the compression index and the coefficient of permeability both decreased in value as the volume concentration of granular material (glass beads) increased in the mixtures.

(2) From the testing program it was found that the values of the compression index and the coefficient of permeability of the clay-glass beads mixtures were proportional to the values of these parameters for the clay alone, its void ratio, and the percentage by volume of the glass beads in the mixtures. Since clays can be easily tested in conventional laboratory equipment, this finding is of great paractical importance for the estimation of these parameters for the case of clay-rock mixtures.

(3) From direct shear tests on mixtures of clay and Ottawa sand it was found that the percentage of sand in the mixtures had a marked influence on the shear strength of the mixture. It was found that when the volume concentration of the sand varied between 100% and 80%, the shear strength of the mixtures was governed mainly by frictional resistance between the sand. When the concentration of sand varied between 80% and 50%, the shear strength of the mixture was provided in part by the shear strength of the kaolinite clay and in part by the frictional resistance between the sand grains. When the sand concentration was less than 50%, the shear strength of the mixture was entirely dictated by the strength of the clay.

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