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Fine Particles Translocation During Infiltration into Porous Media

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ABSTRACT

Sand-silt mixtures were used as porous medium packed at two bulk densities to investigate whether the fine particles in the mixture tended to be translocated within the porous medium column as a result of the infiltration process. Gamma-ray attenuation technique was used to detect the translocation process through the measurements of bulk density at different positions in the porous medium columns. The bulk density determination were carried out both before and after the infiltration process. Some suggestions of fine particles translocation out of the top 0.5 and 1.0 cm nearest the upper inlet end of the column was found for the lower bulk density (1.8 gm/cm^3), but not for the higher (1.9 gm/cm^3). The infiltration flow behaviour, however, as analyzed by a derivative form of an approximate theory for infiltration, did not exhibit any non-Darcian behaviour, even for the material of lower bulk density wherein some suggestion of fine-particle translocation had been found.

INTRODUCTION

When water infiltrates into a porous medium, the moving water might carry fine particles and redeposit them somewhere deeper in the porous medium. Swartzendruber (4) gave a possible explanation of the Non-Darcy flow behaviour by postulating that fine particles of the porous medium were being translocated out of the near surface region by the high velocity of the infiltrating water. Any such translocated particles should be redeposited somewhere deeper in the column of the porous medium when the velocity of water movement has substantially decreased. The translocation process should be detectable as a change in porous-medium bulk density when considered as a function of distance below the top surface of the column. With the application of the gamma-ray techniques developed by Gardner (3) it is possible to obtain precise and non-destructive measurements of bulk density versus position both before and after the occurence of water infiltration, and from the measurements the fine particle translocation could be detected.

The objective of this study is to experimentally assess the existence and extend of particle translocation caused by water infiltration in sand-silt mixtures columns by the application of the gamma-ray attenuation technique.

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METHODS AND MATERIAL

Bulk density measurements

The main phase of this study involves the measurements of bulk density changes in a porous medium by the application of gamma-ray attenuation technique.

The gamma-ray apparatus consisted of 250 mc Cs^{137} source, a detecting and analysing system, and a mechanism for positioning the source and detector with respect of the porous medium column. For a dry porous medium (moisture content = 0), the attenuation equation is

$$I_d = I_0 \exp(-Xu_s 1_s - X_c u_c 1_c) \quad (1)$$

where I_0 is the incident flux (counts per unit time) for the gamma-ray source, I_d is the flux having passed through a distance X of porous medium of bulk density 1_s, X_c is container wall thickness. Mass attenuation coefficients for the porous-medium particles and the container wall are u_s and u_c respectively. If I_a is the flux for the empty container tube ($1_s = 0$) the equation is

$$I_a = I_0 \exp(-X_c u_c 1_c) \quad (2)$$

Combining equation (1) with (2) and solving for 1_s yields

$$1_s = I_n(I_a/I_d)/Xu_s \quad (3)$$

The value of 1_s could be calculated by measuring all the quantities in equation (3) by using the gamma-ray apparatus.

Experimental technique

Two plexiglass tubes 40.0 cm long, 6.2 cm inside diameter and of 0.6 cm wall thickness were used as confining columns. The empty tubes were first placed in the gamma-ray apparatus to obtain I_a readings in equation (3) at 0.5 cm increments of tube length. The tubes were then packed with porous material. The porous material used in this study is a mixture on weight basis of 75% banding sand and 25% ground silica. Both of these materials are essentially composed of quartz and the air dry water content of them was zero. To achieve uniform packing the empty confining columns were circumferentially scribed at 2 cm intervals of column length. Equal masses of porous material were then packed into each of 2 cm sections, the amount depending on the bulk density desired. Each individual section was tamped with a large rubber stopper fastened to the end of a long rod. Two bulk densities were used, the first was 1.8 gm/cm^3, and the second was 1.9 gm/cm^3. After packing, gamma-ray measurements at each 0.5 cm position in the porous medium columns were obtained, and calculation of 1_s from equation (3) was done at each 0.5 cm position. An average bulk density was calculated from the total dry mass of porous medium in the column divided by the total volume of the column, and this average value of bulk density u_s was used along with the average value of all (I_a/I_d) at each position. After determination of bulk density at each 0.5 cm position, the porous medium columns were then positioned vertically and subjected to downward infiltration using constant head applicator (5).

The volume of infiltrated water was recorded from a flow meter. Wet front progress was recorded by means of circumferential scribe marks placed every 2 cm on the exterior of the porous-medium plexiglass tube. After infiltration and when the wet front reached the lower end of the porous medium column, a slightly warmed air was forced through porous medium columns at a slow rate until all water had been removed. The drying was determined by precise weighing of each column compared with its initial dry weight prior to infiltration. Each dried column was then placed horizontally into the gamma ray apparatus to obtain a second set of I_d readings at each 0.5 cm position, with 1_s again calculated from equation (3). Thus it was possible to obtain precise and nondestructive measurements of bulk density versus position, both before and after the occurrence of water infiltration. If fine particles were translocated out of the water-inlet region of the column and redeposited at some deeper position, a corresponding shift in the bulk density distribution should be detectable. From the infiltration data a test of flow deviation was possible to determine whether this flow deviation was possible to determine whether this flow deviation, if any, could be meaningfully related to any shift in the bulk density distribution.

RESULTS AND DISCUSSION

First aspects to be considered will be the bulk densities determined from equation (3) by gamma ray measurements at 0.5 cm positions along the column. Plots of bulk density versus position, both before and after infiltration, are shown in Figure 1 for the mean bulk density 1_s of 1.8 gm/cm^3. Fluctuation of bulk density both before and after infiltration are within a band of $\pm 4.4\%$ of the mean and there is no evidence within this band of any consistent trend with position. This demonstrates an acceptable degree of uniformity in packing. Near the inlet end of the column, however, the bulk density after infiltration appears to be slightly reduced from its value before infiltration, consistent with the possibility that fine particles may have been translocated out of this region by infiltration. The difference is most pronounced at 0.5 and 1.0 cm, but it must also be granted that reductions of almost the same magnitude are present at 7.5 and 36.5 cm below the inlet end of the column. Even if the reductions near the inlet end are accepted as real, any redeposition of these translocated particles appears to be redistributed rather evenly over the remainder of the column since there is no subsequent part that appears to stand out as a region of bulk density enhancement. In this respect the gap in the pre-infiltration data from 5.0 to 7.0 cm is unfortunate. It was caused by a plexiglass supporting bracket which was judged too difficult to shift without causing possible disturbance to the column.

Graphical results for the column of mean bulk density 1.9g/cm^3 are shown in Figure 2. Fluctuation of bulk density are within a band of $\pm 5.8\%$ of the mean, which is somewhat higher than that in Figure 1 but is nevertheless quite similar. Also, there is little evidence within the band of any consistent trend with position, thus again demonstrating an acceptable degree of uniformity in packing. There is distinctly less indication than in Figure 1 of any change in bulk density as possibly attributable to infiltration, except for the reduction at 27.5 cm which is very easily accounted for by an obvious drying-induced crack observed to be in line with the direction of the gamma-ray beam at that point. In actuality, the possibility of fine particle translocation in this column was expected to be minimal because of the high bulk density, and the data in Figure 2 generally confirm this expectation.

The next thing to be examined by using the infiltration data obtained in this study, is to test for any non-darcian behaviour which might have been caused by particle translocation. This deviation flow behaviour was reported by Swartzendruber (1968) when he examined an infiltration equation given as

$$y\,dy/dt = ac + Cy \tag{4}$$

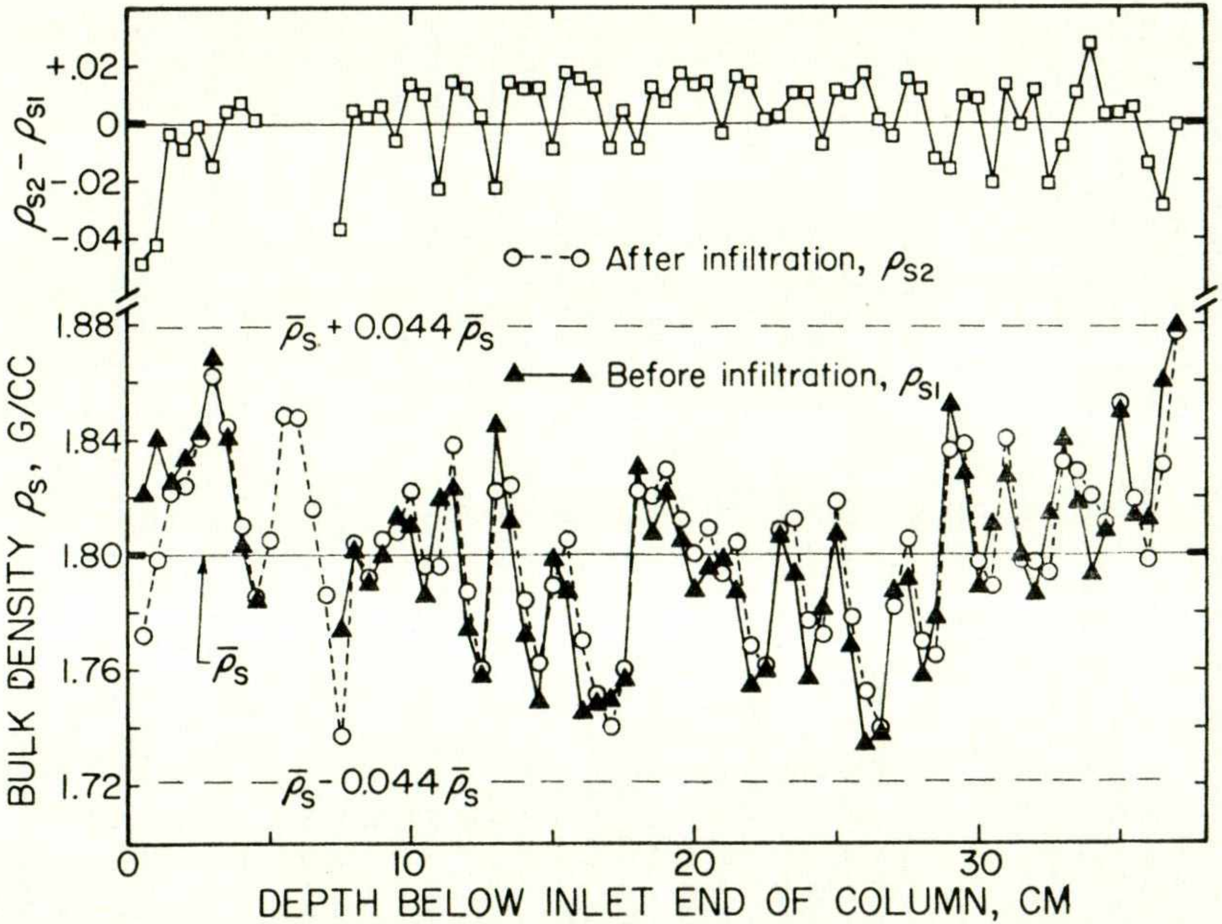

Fig. 1. Bulk density versus position for fine material of mean bulk density 1.8 g/cc

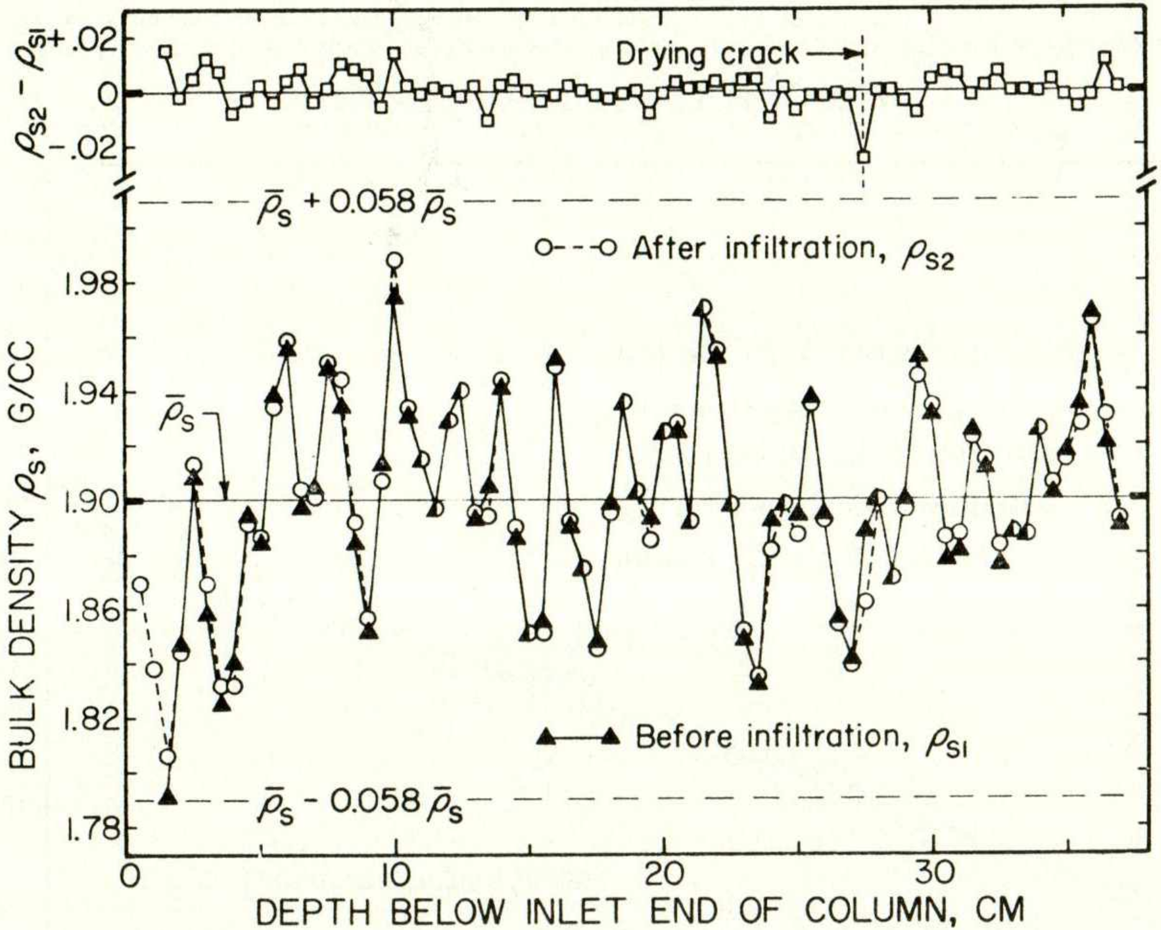

Fig. 2. Bulk density versus position for fine material of mean bulk density 1.9 g/cc

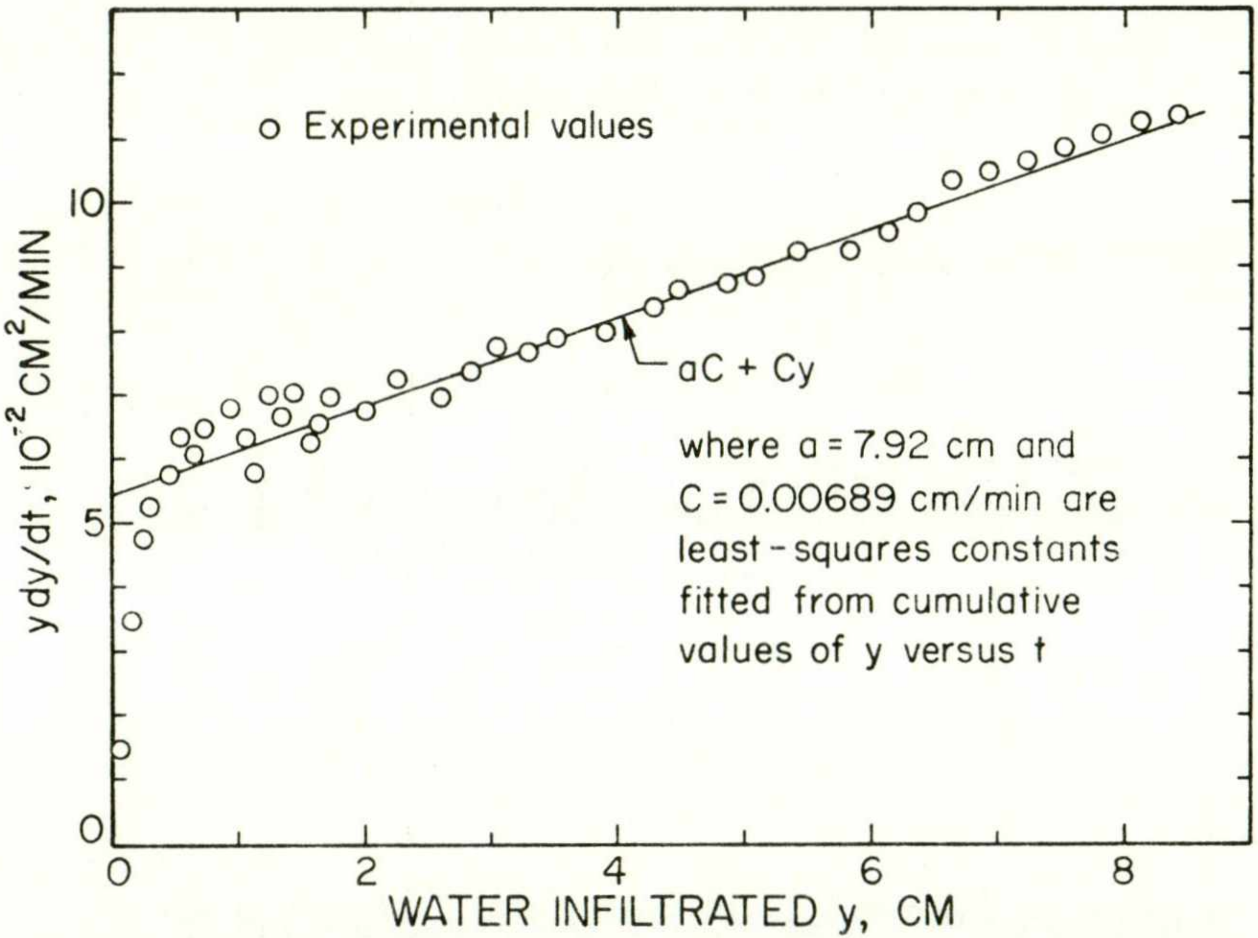

Fig. 3. Plot of y dy/dt versus of (equation (4)) for a mean bulk density of 1.8 g/cc values of C and a obtained by a least square fit of infiltration equation to the cumulative values of y and t.

where y is the volume of water transmitted per unit cross sectional area of soil column, t is the time, a and C are parameters characterizing the porous medium. A plot of (y dy/dt) versus y should yield a straight line of slope C and intercept aC. However data have been reported by Swartzendruber (1968), in which y dy/dt initially decreased with increasing y, reached a minimum value and then eventually did increase approximately linearly with increasing y.

The infiltration data in our study could be used as a test for this deviation behaviour. The infiltration data in this study were analyzed on the basis of the sliding least square derivative technique developed for an approximate infiltration theory by Mohamed Asseed and Dale Swartzendruber (1,2). After fitting the infiltration data the parametres a and C of equation (4) were evaluated. The plot of (y dy/dt) versus y is shown in Figure 3 for the porous medium column of bulk density 1.8 gm/cm^3. It is quite clear that there is no initial region of negative slope. Furthermore, the straight line ac + Cy (equation (4)) established from a and C determined from the least square fit, goes through the experimental points very nicely. Hence we are left with the conclusion that if the reduction in bulk density at 0.5 and 1.0 cm in Figure 1 reflects a real translocation of fine particles, the effect is not great to cause anomalous infiltration deviations from equation (4). On the contrary, the first four points of Figure 3 are actually below the line specified by the subsequent points. Such behaviour can be rationlized on the basis that the infinite initial dy/dt required by equation (4) cannot truly be realized physically. Rather, in starting from essential rest at t = 0, the rate dy/dt. of the infiltration process will at first be less than infinite, eventhough it is very large. Hence, y dy/dt. will initially lag the values required theoretically be the straight line passing through the later values that are linearly confirming.

A similar graph to Figure 3 was also prepared for a porous medium column of bulk density 1.9 gm/cm^3, but it is not presented here because it shows essentially the same agreement between data and straight line as does Figure 3. This of course would have been expected, since in the basis of Figure 2 there was no real evidence of fine-particle translocation from the region near the inlet end of the porous medium column.

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ظاهرة انتقال الحبيباب الدقيقة فى الوسط النفاذى عند انسياب المــاء فى التربة

محمد شعبان السيد ، ديل سوارزن روبر

المستخلـــــص

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