

ELECTROLYTE CONCENTRATION-PERMEABILITY RELATIONSHIPS IN SODIUM ILLITE-SILT MIXTURES

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Abstract—To examine the effects of clay swelling and dispersion on electrolyte concentration–permeability relationships of low clay content soils, flow experiments were conducted on a silt of fixed particle size distribution containing 0, 5, 7.5, 10 and 15 per cent clay (sodium illite, 2 μm fraction). Flocculated specimens were sedimented using both slow and rapid procedures. After compression each specimen was permeated successively with electrolyte solutions which caused (1) swelling of the clay fraction (0.10 N), and (2) dispersion (0.05 N). Absolute permeabilities varied with clay content, sedimentation procedure, compression rate, and electrolyte concentration; however, the form of this variation plotted against through-put volume was similar for all specimens containing electrolyte solutions causing only swelling of the clay. Increasing the hydraulic gradient above a critical value apparently increased the swelling slightly as evidenced by further reductions in permeability. The permeability of mixtures permeated with electrolyte solution causing dispersion of the clay was more complex and depended on clay content, the hydraulic gradients used to introduce the dispersing electrolyte solution and the pre-dispersion gradients to which the specimens had been subjected. Permeability decreases were attributed to the last stages of swelling prior to dispersion and to pore plugging. Increases in permeability were the result of erosion of dispersed particles. Specimens previously subjected to the highest gradients while swelling dispersed more rapidly and had a greater tendency to erode. The effects of predispersion gradients diminished with increasing clay contents. It is concluded that both compositional and mechanical factors play an important role in determining electrolyte concentration–permeability relationships for soils containing active clay minerals.

INTRODUCTION

Recent studies have indicated that deposits containing small amounts of clay play an important role in the movement of water within layered groundwater basins (California Department of Water Resources, 1971). As a result of seawater intrusion into coastal basins and groundwater recharge through previously intruded layers, deposits containing small amounts of clay can be subjected to large and relatively rapid changes in pore solution electrolyte concentration and cation types.

This paper presents the results of an experimental investigation on artificially sedimented mixtures containing small amounts of clay. The study was conducted to examine the influences of selected compositional and mechanical parameters on relationships between compression, permeability, and electrolyte concn changes. The grain size distributions and the range of electrolyte concentration used were selected to simulate conditions which occur in sediments of a coastal groundwater basin.

BACKGROUND

In soils containing clay minerals, changes in pore soln chemistry and mechanical factors can cause changes in permeability. For soils containing adsorbed sodium cations, variations in pore water electrolyte concentration cause changes in the colloidal state of the clay particles. Decreases in electrolyte concentration may cause substantial swelling and dispersion. Reductions in permeability accompanying clay swelling have been attributed both to changes in adsorbed water structure (Lutz and Kemper, 1959; Miller and Low, 1963), and to reductions in average pore sizes as a result of particle swelling and reorientations (McNeal and Coleman, 1966; Lagerwerff *et al.*, 1969). Decreases in permeability following clay dispersion have been attributed to particle migrations and pore plugging (Martin, 1962; Gray and Rex, 1966). Increases in permeability after clay dispersion can occur when fluid conducting pores remain large enough to permit erosion of dispersed particles (Aitchison and Wood, 1965).

Understanding of electrolyte concentration-permeability relationships derived from the cited studies and others has been applied in a practical way to permeability maintenance in agricultural soils (Reeve and Doering, 1965) and to the determination of the suitability and treatment of compacted clays for embankments and dams (Ingles and Aitchison, 1969). Both these general soil groups may be subjected to large changes in pore solution chemistry within short time periods as a result of natural phenomena and human activities.

The influence of pore solution chemistry on the absolute permeabilities and compression behavior of saturated, predominantly clay soils has also been studied extensively (Macey, 1942; Michaels and Lin, 1954; Mesri and Olson, 1971). The effects of mechanical factors and chemical changes on post-consolidation permeabilities have been studied to a lesser extent.

Mechanical factors alone may produce permeability changes. Blackmore and Marshall (1965) suggested that for flow through systems with oriented clay particles, hydraulic gradients can cause clay consolidation and permeability decreases. Particle reorientations occurring as a result of seepage forces have been postulated as a reason for observed non-Darcy permeability-hydraulic gradient relationships (Terzaghi, 1925; Miller *et al.*, 1969). Mitchell and Younger (1967) observed that both the magnitude and direction of the seepage forces affected measured permeabilities. Olsen (1965, 1966) reviewed the evidence for non-Darcy flow and concluded that realistically low hydraulic gradients (i.e. those approaching field values) could cause permeability changes as a result of fabric changes in

shallow unconfined clays as well as in confined granular deposits containing small amounts of clay.

The review above indicates that both chemically and mechanically induced changes in permeability can occur in a variety of soils. Granular sedimentary deposits containing small amounts of clay may be especially susceptible to seepage induced fabric changes. Under conditions of seawater intrusion and recharge, these deposits may experience rapid changes in electrolyte concentration under varying hydraulic gradients.

MATERIALS AND TEST METHODS

The compositional parameters investigated were clay content and electrolyte concentration. Mechanical variables included sedimentation procedure, compression procedure, and hydraulic gradient.

Compression and direct permeability tests were conducted on mixtures of a sodium illite (particles finer than $2\ \mu\text{m}$) and a ground basalt. The illite was fractionated from Grundite. From qualitative X-ray diffraction analyses, it was estimated that the $<2\ \mu\text{m}$ fraction contained small amounts of kaolinite, interstratified kaolinite and illite, and quartz in addition to the illite. The basalt was processed from Napa basalt and contained principally plagioclase feldspars, olivine, and pyroxene. The illite was sodium saturated by several cycles of washing and centrifugation in 1.0 N soln NaCl at pH 7. The exchange capacity of the illite at pH 7 was 35 m-equiv/100 g⁻¹. The ground basalt contained a uniform distribution of sizes from 2 to 300 μm . The grain size distributions of the illite-basalt mixtures tested fall within the range shown in Fig. 1.

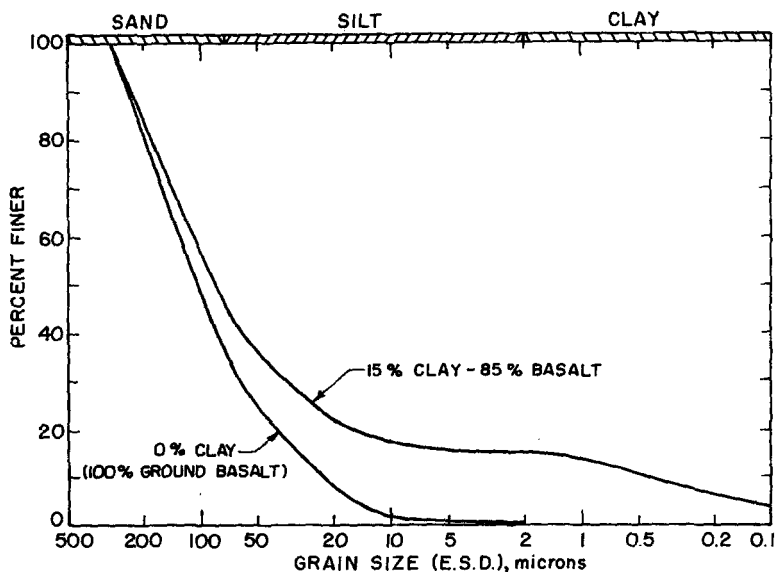


Fig. 1. Range of grain size distributions.

Batches of each mixture were prepared to provide at least two specimens containing 0, 5, 7.5, 10 and 15 per cent clay for sedimentation into Lucite cylinders. The cylinders were 50 cm in length and 6.35 cm i.d. All mixtures were prepared in solutions of NaCl at a concentration approximating the total electrolyte concn of seawater (0.6 N).

Two procedures were used to sediment the mixtures. A slow sedimentation technique was used in an attempt to achieve an initially open flocculated soil structure. This procedure consisted of depositing daily, for approx 20 days, 25 cm³ aliquots of the saturated homogenized mixtures using a 1 cm dia. pipet. The weight of solids in each aliquot averaged 7 g. The pipet was inserted just beneath the surface of a 2 cm thick supernatant layer of 0.6 N NaCl solution in the sedimentation cylinder. The mixture in the pipet was slowly and uniformly released over the area of the cylinder. After consolidation under its own weight, each completed deposit was consolidated in the cylinders under pressure increments of 0.0625 kg cm⁻² day⁻¹ until a final effective consolidation pressure of 0.5 kg cm⁻² was reached. Deposition and consolidation required approx 30 days to complete.

A rapid sedimentation procedure was also used in order to assess the role of initial fabric on the subsequent behavior of the mixtures. Since undisturbed samples of saturated granular materials containing only small amounts of clay are not easily obtained in the field, comparisons with specimens prepared by the slow procedure allow an evaluation of the potential of using reconstituted field samples for determination of

the effects of electrolyte concn changes on permeability.

In the rapid procedure, slurried mixtures containing the desired proportions of clay and silt were poured directly into dry sedimentation cylinders and immediately consolidated to a pressure of 1.0 kg cm⁻² in increments of 0.0625 kg cm⁻² applied at intervals of 12 hr.

The total solution contents at deposition varied from 110 per cent of the dry soil weight for mixtures containing 15 per cent clay to 50 per cent of the dry soil weight mixtures containing 5 per cent clay.

When consolidation in the cylinders was complete, each mixture was extruded directly into the 6.35 cm dia., 2.54-cm thick Teflon-lined sample ring of the permeability-consolidation flow cell.

The flow cell and its associated flow control system are illustrated schematically in Fig. 2. The system allowed for measurement of specimen compression and permeability at any time. The bleed and flush valves facilitated rapid and complete solution changes in the system. The porous stones above and below the test specimen could be flushed continuously while maintaining a hydraulic gradient across the specimen. The stones were so flushed except during actual permeability measurements. Degassed solutions were used for all flow tests. The experiments were conducted in a laboratory maintained at a constant temperature of 20°C.

Total and differential porewater pressures were controlled by applying air pressure to nylon discs floating on the surfaces of the reservoir soln and were measured

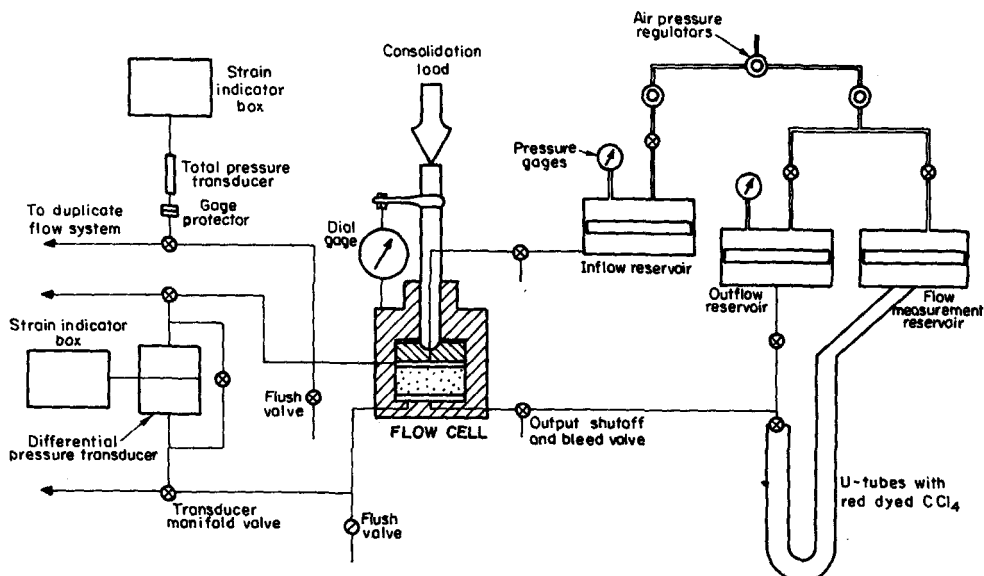


Fig. 2. Permeability-compression test apparatus.

by total and differential pressure transducers connected to the porous stones above and below the test specimens. Flow rates were calculated by measuring the travel of a red-dyed carbon tetrachloride-water interface in the calibrated U-tubes. Direct permeability measurements were made at equilibrium void ratios corresponding to several consolidation pressures to a maximum consolidation pressure of 32.0 kg cm^{-2} . Void ratio is defined as the vol of voids per unit vol of oven-dried mineral solids and is designated by the letter *e*. Post-consolidation void ratios were calculated from test specimen height changes and the known initial void ratios of the specimens.

Most specimens were compressed by doubling the effective consolidation pressure every 24 hr. In order to compare the compression behavior of specimens compressed at a faster average rate, four specimens were consolidated using pressure increments of $1.0 \text{ kg cm}^{-2} \text{ hr}^{-1}$.

After compression to effective pressures of 32.0 kg cm^{-2} , with permeability measurements at each pressure, specimens were permeated successively under controlled hydraulic gradients with electrolyte solution which caused (1) clay swelling (0.1 N NaCl) and (2) clay dispersion (0.05 N NaCl). The first visual observation of turbidity in the effluent was considered to be evidence of particle dispersion. After dispersion, and for some specimens after considerable erosion of dispersed particles, 0.6 N NaCl soln were reintroduced. The term erosion as used herein refers to the entrainment and removal of dispersed particles from the specimen following the initial detection of effluent turbidity.

Hydraulic gradients were varied in order to observe the effects of seepage forces on measured permeabilities and erosion. For specimens experiencing erosion, corrected clay contents were calculated from the weight of the eroded material.

TEST RESULTS

The compression characteristics of slowly and rapidly-sedimented mixtures are shown in Figs. 3 and 4. Compression curves for initially dense and loose ground basalt with no clay added are also included in Fig. 3.

The compression curves show that compressibility increases with clay content for samples prepared by both sedimentation procedures. At equal clay contents, the slow-sedimented mixtures have higher void ratios than rapid sedimented mixtures at the same effective pressure. This result indicates that the slow sedimentation procedure was successful in producing a more open structure in comparison to the rapid procedure. Sediment volume-initial structure relationships for these low clay content mixtures are similar to those of sedimented and remolded soils containing much larger amounts of illite (Bjerrum and Rosenqvist, 1956).

Figure 4 compares the effects of average compression rate on the compression of slowly-sedimented mixtures containing 10 per cent clay. No major differences in compression behavior were observed due to different rates of compression.

The variation in hydraulic conductivity with void ratio is shown for three clay contents in Fig. 5. For the

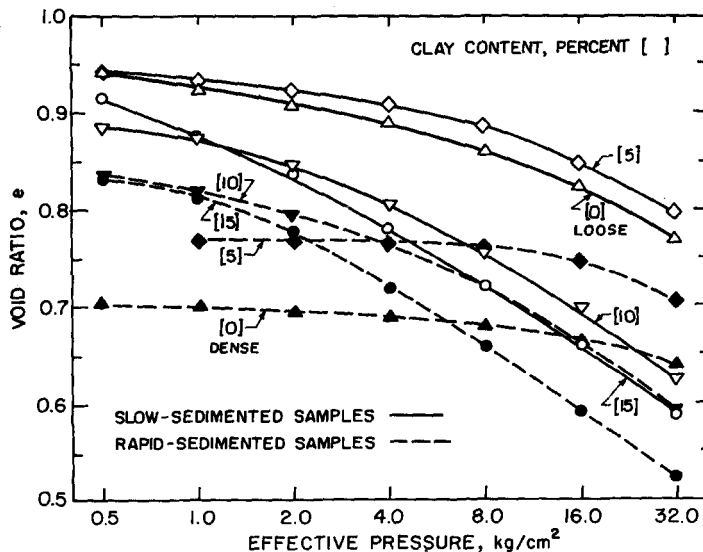


Fig. 3. One-dimensional compression characteristics.

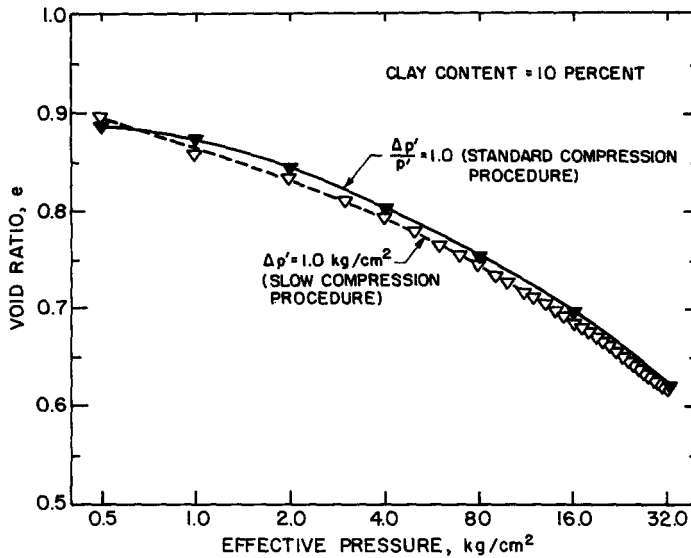


Fig. 4. Comparison of compression procedures.

same average soil void ratio, permeability, expressed as hydraulic conductivity at 20°C, decreases with increasing clay content. The conclusion that the slow sedi-

mentation procedure produced a more open flocculated structure within the clay is generally borne out by the permeability data.

There is no apparent explanation for the anomalous relationship of the mixtures containing 5 per cent clay, however.

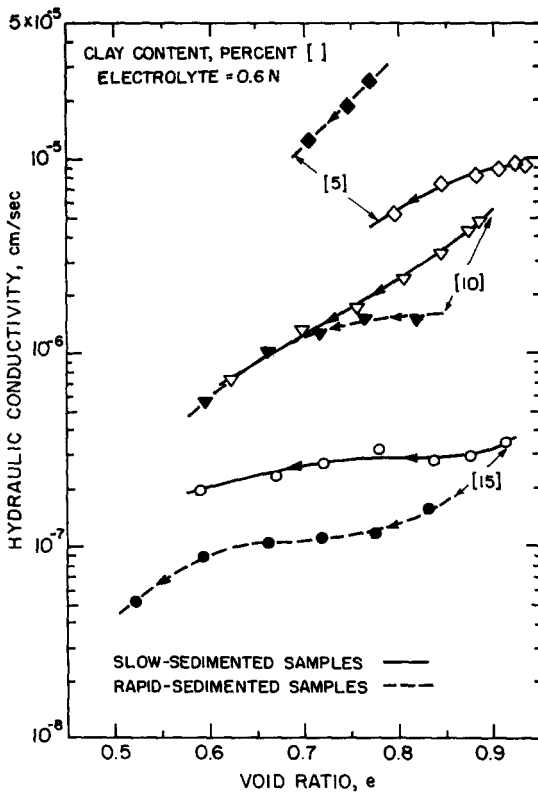


Fig. 5. Hydraulic conductivity–void ratio relationships.

Figure 6 illustrates changes in permeability which occurred while the electrolyte concentration of the pore solution was changing from 0.6 to 0.1 N. Solutions at these concentrations are referred to herein as flocculating and swelling electrolytes, respectively. The permeability changes shown in Fig. 6 and those following are normalized with respect to the equilibrium hydraulic conductivities of each mixture existing prior to the last change in electrolyte concentration. To facilitate comparisons of mixtures of different void ratios and permeabilities, the normalized hydraulic conductivities are plotted against normalized cumulative throughputs. The normalized cumulative throughput is the sum of each increment of flow vol. Q , in cm^3 , divided by the specimen pore vol. V_v , in cm^3 . Although void vol varied with clay content, sedimentation procedure and effective consolidation pressure, none of the mixtures experienced changes in average soil void ratio when permeated with the 0.1 N electrolyte.

The data points of Fig. 6 for 5 and 15 per cent clay mixtures are typical of the data observed for all clay mixtures tested during swelling of the clay. The data show that equilibrium hydraulic conductivities were reached after 1–2 pore vol of 0.1 N solution had permeated the mixtures. The envelope of hydraulic conductivity reductions in Fig. 6 indicates that for mixtures containing up to 15 per cent clay, the form of

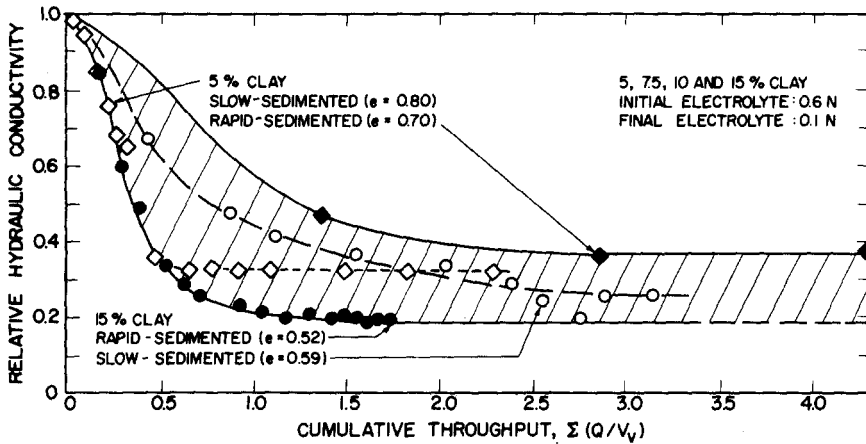


Fig. 6. Hydraulic conductivity reductions as a result of clay swelling.

the decrease is independent of clay content and of the two sedimentation procedures used.

The maximum hydraulic gradients to which the mixtures containing 5 and 15 per cent clay were subjected while permeated with 0.1 N electrolyte were 5.4 and 63, respectively. The lower of these values is typical of those used for mixtures with less than 15 per cent clay. Hydraulic gradients were selected from consideration of the time required for testing and the need to keep gradients as low as possible. In fact, natural hydraulic gradients in the field rarely exceed unity (Mitchell and Younger, 1967).

Selection of the proper gradients to use in permeability testing of natural clayey soils has seldom been

based on duplicating gradients in the field. Some consideration has been given to limiting seepage forces to arbitrary small fractions of the existing intergranular pressures. (Olsen, 1962; Mitchell, 1969). For mixtures containing only small amounts of clay within a granular skeletal structure, the usefulness of the latter approach is questionable. For such mixtures, clay minerals within the void space defined by the non-clay skeleton grains are more free to respond to changes in chemical environment and to seepage forces than are clay particles subject to high intergranular stresses.

Rowell *et al.* (1969) demonstrated that seepage forces can provide the energy necessary to surmount barriers preventing dispersion. These writers suggested that the

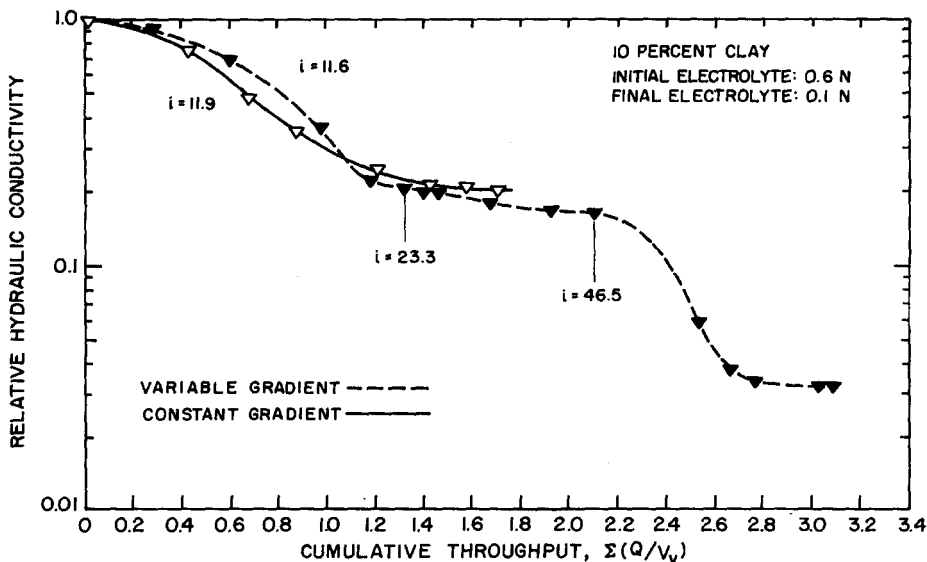


Fig. 7. Influence of hydraulic gradient on hydraulic conductivity reductions caused by swelling.

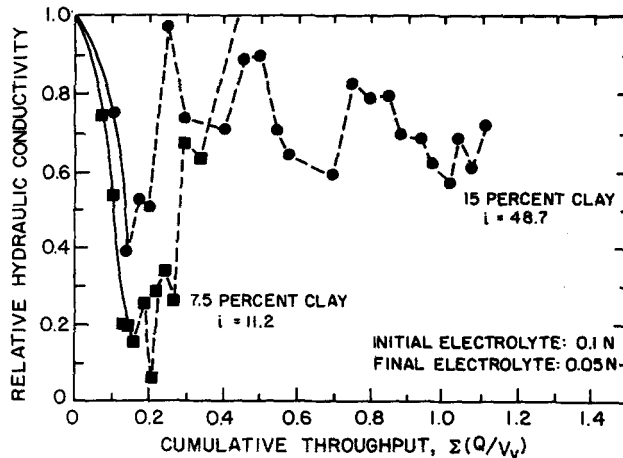


Fig. 8. Hydraulic conductivity changes associated with permeation by dispersing soln.

electrolyte concn at which clay dispersion occurs increases with the magnitude of the applied seepage forces.

Figure 7 suggests that the magnitude of the seepage forces also affects swelling. Increasing the hydraulic gradient after an apparent equilibrium condition had been obtained with 0.1 N electrolyte caused an additional decrease in permeability. The regularity of the decrease and the fact that no turbidity was observed in the throughput suggest that the permeability decrease was due to additional swelling. Generalization of this effect was not established. However, it is clear from both theoretical potential energy-particle spacing relationships (Ingles, 1968) and from experimental results

that the magnitude of the seepage forces can influence the swelling of the unconfined clay in the mixtures.

Shown in Figs. 8 and 9 are hydraulic conductivity changes for mixtures permeated with solutions of electrolyte concentration sufficiently low (0.05 N) to cause dispersion. The 7.5, 15 and one of the 10 per cent clay mixtures demonstrate additional permeability decreases below the equilibrium values at 0.1 N NaCl. The regularity of the decrease and the initially non-turbid throughput suggest that additional swelling occurred prior to dispersion. This last stage of swelling may be due to mixing of the 0.1 and 0.05 N solution.

Clay particles were washed out of all mixtures with less than 15 per cent clay after permeation with 0.05 N

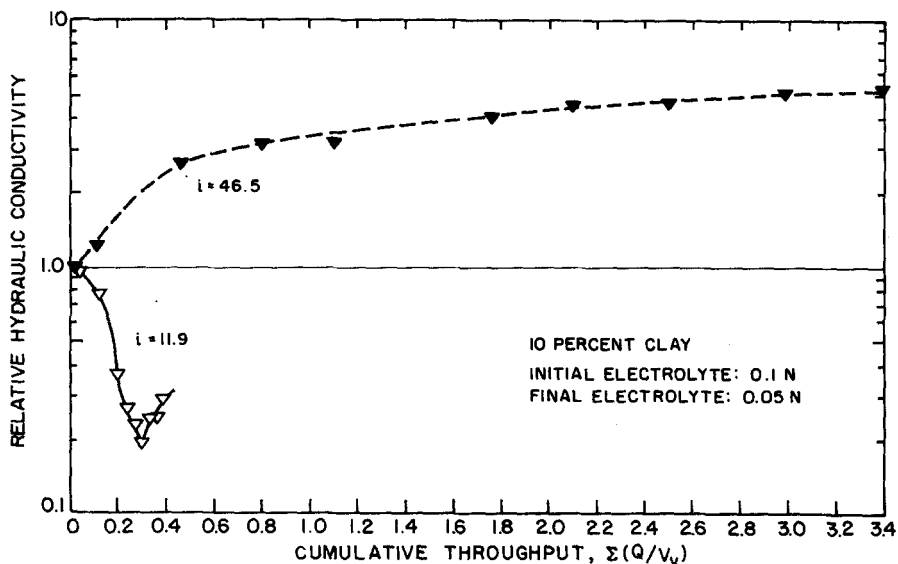


Fig. 9. Effect of gradient on hydraulic conductivity changes accompanying permeation by dispersing solution.

electrolyte. No clay erosion was observed in the mixtures containing 15 per cent clay even at the largest hydraulic gradients used (48.7). The erratic variation in hydraulic conductivity of the 15 per cent clay mixture of Fig. 8, is attributed to particle migration. The average permeability of this mixture after continued permeation with the dispersing electrolyte was slightly less than the equilibrium permeability during permeation with the swelling electrolyte (0.1 N NaCl).

Figure 9 illustrates the influence of hydraulic gradient differences on the dispersion and erosion of particles from 10 per cent clay mixtures. The mixture in the upper half of Fig. 9 had experienced larger hydraulic gradients than the mixture in the lower part of the figure during permeation with the swelling electrolyte. The immediate onset of erosion (highly turbid throughput) is attributed both to the higher gradients applied during permeation with the dispersing electrolyte and to the previous higher gradients during swelling. The conclusion that the predispersion gradient is in part responsible for immediate dispersion and erosion is based on the arguments of Rowell and his co-workers cited previously and on the behavior of a mixture containing 5 per cent clay. The specimen, which had been subjected to a gradient of 5.4 while swelling, immediately eroded when permeated with 0.05 N solution, whereas one which experienced a gradient of 4.2 while swelling did not immediately disperse.

The relationships between permeability and hydraulic gradient discussed in the preceding paragraphs illustrate the effects of sustained seepage forces of differing magnitudes on the equilibrium permeability ultimately obtained at a particular electrolyte concentration. The effects of changes in hydraulic gradient on the apparent equilibrium permeability as illustrated in Fig. 7 are designated long-term gradient dependencies, since they reflect the influence of both the duration of application and the magnitude of the seepage forces.

A second type of gradient dependency, herein called short-term, is illustrated in Fig. 10. The variations in relative hydraulic conductivity were observed while successively increasing and decreasing the gradient. Each gradient was applied only for the time necessary to make two measurements of hydraulic conductivity. The mixture was in chemical equilibrium with either the dispersing (0.05 N) or the flocculating (0.6 N) soln when the measurements were made. The apparent short term gradient dependency of the dispersed mixture is attributed to irreversible fabric changes. An extremely small amount of clay was eroded from this mixture during the period in which the hydraulic gradient was varied.

The mixture demonstrating short term gradient dependency at 0.05 N NaCl was relatively stable after

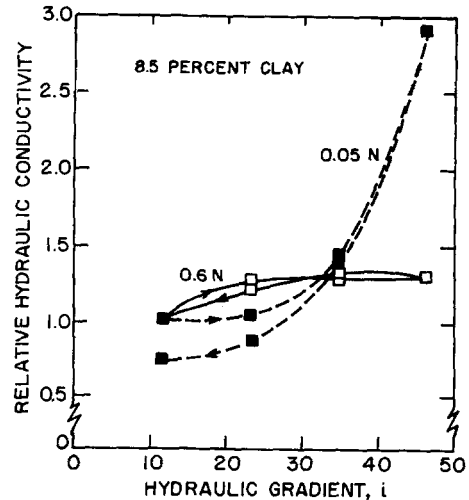


Fig. 10. Short term dependence of hydraulic conductivity on gradient.

reflocculation with 0.6 N NaCl. The short term hydraulic gradient relationships during permeation of mixtures with swelling electrolyte solution (0.1 N) were similar to those for the 0.6 N solution. These test results coupled with the data of Fig. 7 indicate that for mixtures in which the clay was swelling but not dispersing, gradient dependent hydraulic conductivity changes occur only after substantial flow has taken place under the increased hydraulic gradient.

The final phase of the testing program consisted of reintroducing 0.6 N electrolyte solution into each mixture. Figure 11 shows the increases in relative hydraulic conductivity after such reintroduction into mixtures containing 5 and 10 per cent clay. The 10 per cent clay mixture in the upper part of the figure had been previously permeated with 0.1 N NaCl only, whereas the 5 and 10 per cent mixtures in the lower part of Fig. 12 had been successively permeated with 0.1 and 0.05 N solution. The 0.17 N solution caused one-half the relative hydraulic conductivity decrease produced by the 0.1 N solution. For the two mixtures permeated with 0.1 and 0.05 N electrolyte solution permeation at 0.05 N was immediately discontinued at the onset of turbidity.

The data of Fig. 11 are considered to be an indication of the reversibility of permeability reductions caused by swelling and dispersion. In terms of relative hydraulic conductivities, the increases after reflocculation were approx 20 per cent of the minimum equilibrium value for both swelled and dispersed mixtures. The hydraulic conductivity of the swelled mixture increased from 43 per cent of the original value to 53 per cent; whereas the dispersed mixture increased from 4 to 8 per cent of the original hydraulic conductivity.

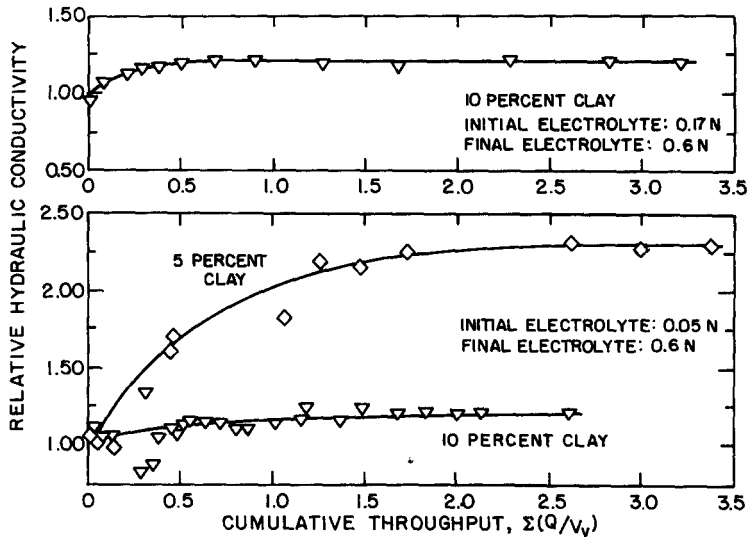


Fig. 11. Reversibility of hydraulic conductivity reductions.

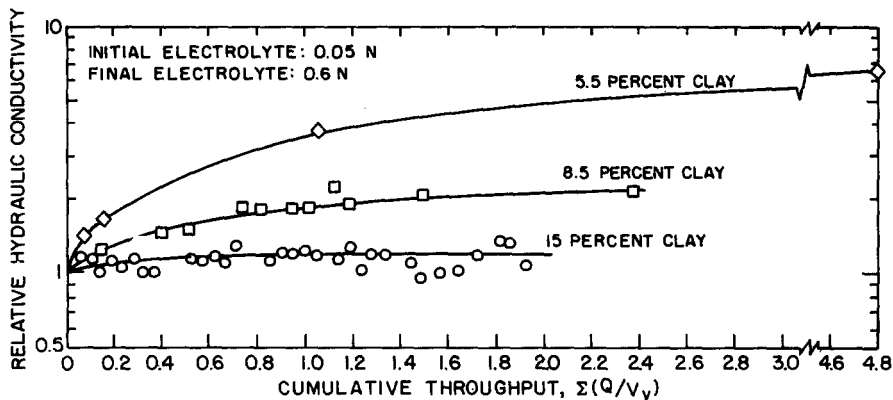


Fig. 12. Hydraulic conductivity increases for reflocculated-dispersed mixtures.

Figure 12 shows the effects of reintroducing electrolyte of the same concentration as sea water (0.6 N) into mixtures which had been previously eroded, or, in the case of the 15 per cent clay mixture, permeated for an extended period (26 days) with the 0.05 N solution. The clay contents shown in the figure were those existing at the time the 0.6 N solution was reintroduced. Erosion immediately ceased after reintroduction of the 0.6 N solution. Although it is questionable whether the clay remaining in the eroded mixtures was uniformly distributed Fig. 12 shows that the magnitude of the relative hydraulic conductivity increase is inversely proportional to the clay content of the mixture. The increases in relative permeability of the non-eroded mixtures of Fig. 11 were considerably smaller than those of the eroded mixtures of Fig. 12, but the relationship between the increases and the clay contents is similar.

SUMMARY AND CONCLUSIONS

The influences of clay content, sedimentation procedure, compression rate, and hydraulic gradients on electrolyte concentration-permeability relationships were investigated for artificial sodium illite-silt mixtures designed to simulate aquitard sediments. After sedimentation using two procedures and compression at two rates, mixtures containing up to 15 per cent clay were permeated successively with NaCl solution causing (1) swelling (0.1 N), and (2) dispersion of clay particles (0.05 N). Following varying amounts of permeation with the dispersing solution the solutions of the same electrolyte concentration used for sedimentation (0.6 N NaCl) were reintroduced.

Permeabilities of the mixtures varied with clay content, sedimentation procedure (initial structure), hydraulic gradients and electrolyte concentration. A slow

sedimentation procedure produced a more open structure than did a rapid procedure, as evidenced by larger void ratios at all values of effective pressure, and, except for the 5 per cent clay specimens, higher permeabilities at equal void ratios. Compression rate differences did not significantly influence the void ratio–effective pressure relationships.

When normalized in terms of the initial permeabilities and void volumes, changes in permeability following permeation with the electrolyte concn which produced clay swelling (0.1 N NaCl) were similar for all mixtures. The form of the variation in permeability was independent of clay content, sedimentation procedure (initial structure) and compression rate. Hydraulic gradients apparently affected electrolyte concn permeability relationships during permeation of the 0.1 N electrolyte solutions. Increasing the hydraulic gradient after an equilibrium permeability was obtained caused further permeability reductions in a 10 per cent clay mixture.

Permeability changes in response to electrolyte concn changes causing dispersion varied with clay content, hydraulic gradients used to introduce the dispersing electrolyte, and the gradients to which the mixtures had been subjected previously while permeated with the solutions causing swelling. Mixtures containing 15 per cent clay showed evidence for particle migration and a net decrease in permeability after dispersion regardless of hydraulic gradient. Clay particles were eroded from mixtures containing 10 per cent or less clay resulting in permeability increases. The onset of erosion after introduction of the dispersing electrolyte soln occurred more rapidly for mixtures subjected to the highest gradients while swelling and dispersing.

Permeability increases after reintroduction of the concentrated electrolyte solution (0.6 N) were smaller than the decreases attributed to either swelling or dispersion. Increases in permeability appeared to be due to a slight reduction in clay swelling. The degree to which relative permeabilities increased for both eroded and dispersed mixtures was inversely related to clay content.

Specific test results are limited to the mixtures and procedures used. In natural sediments, stabilizing agents such as organic material and the natural cementing compounds present in many sediments may reduce the effects observed. However, the results of the tests conducted here suggest that test procedures and techniques must be carefully controlled if electrolyte concentration–permeability relationships of soils containing small amounts of active clay minerals are to be systematically interpreted.

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ior of aquitard sediments conducted at the University of California supported in part by the California Department of Water Resources and by the Marine Minerals Technology Center of the National Oceanic and Atmospheric Administration.

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Résumé—Afin d'étudier les effets du gonflement et de la dispersion de l'argile sur les relations perméabilité—concentration en électrolyte de sols à basse teneur en argile, on a effectué des expériences d'écoulement sur un limon dont la distribution des tailles particulières était fixe et qui contenait 0, 5, 7,5, 10 et 15 pour cent d'argile (illite sodique, fraction 2 μm). Les échantillons floculés ont été sédimentés au moyen de techniques lentes ou rapides. Après compression, chaque échantillon a été percolé successivement par des solutions d'électrolyte qui ont entraîné (1) le gonflement de la fraction argileuse (0,10 N) et (2) la dispersion (0,05 N). Les perméabilités absolues varient avec la teneur en argile, la technique de sédimentation, la vitesse de compression et la concentration en électrolyte; cependant, la forme de cette variation portée en fonction du volume percolé est semblable pour tous les échantillons contenant des solutions d'électrolytes qui n'entraînent que le gonflement de l'argile. L'augmentation du gradient hydraulique au-dessus d'une valeur critique entraîne apparemment une légère augmentation du gonflement comme le montrent les diminutions ultérieures de la perméabilité. La perméabilité des mélanges percolés avec des solutions d'électrolyte entraînant la dispersion de l'argile est plus complexe et dépend de la teneur en argile, des gradients hydrauliques utilisés pour introduire la solution d'électrolyte dispersante et des gradients de prédispersion auxquels les échantillons sont soumis. Les diminutions de perméabilité ont été attribuées aux dernières étapes du gonflement précédant la dispersion et le bouchage des pores. Les augmentations de la perméabilité sont le résultat de l'érosion des particules dispersées. Les échantillons soumis initialement aux plus forts gradients pendant le gonflement dispersent plus vite et ont une tendance accrue à l'érosion. Les effets des gradients de prédispersion diminuent quand les teneurs en argile augmentent. On en conclut que des facteurs à la fois texturaux et mécaniques jouent un rôle important dans la détermination des relations perméabilité—concentration en électrolyte pour des sols contenant des minéraux argileux actifs.

Kurzreferat—Um die Einflüsse von Tonquellung und Dispergierung auf die Beziehung zwischen Elektrolytkonzentration und Permeabilität in Böden mit geringem Tongehalt zu untersuchen, wurden Durchlaufversuche an einem Schluff mit festgelegter Teilchengrößenverteilung der 0, 5, 7, 5, 10 und 15% Ton (Natriumillit, <2 μm -Fraktion) enthielt, durchgeführt. Geflochte Proben wurden unter Verwendung sowohl langsamer als auch schneller Verfahren sedimentiert. Nach Pressung wurden durch jede Probe nacheinander Elektrolytlösungen perkoliert, die erstens Quellung der Tonfraktion (0,10 N) und zweitens Dispergierung (0,05 N) hervorriefen. Die absoluten Durchlässigkeiten schwankten mit dem Tongehalt, dem Sedimentationsverfahren, der Kompressionsrate und der Elektrolytkonzentration. Wurde diese Veränderung gegen das Durchlaufvolumen aufgetragen, so ergab sich für alle Proben mit Elektrolytgehalten, die eine Quellung des Tons hervorriefen, ein ähnlicher Kurvenverlauf. Die Erhöhung des hydraulischen Gradienten über einen kritischen Wert ließ offensichtlich die Quellung leicht ansteigen, wie eine weitere Verminderung der Permeabilität erkennen ließ. Die Durchlässigkeit von Mischungen, die mit auf den Ton dispergierend wirkenden Elektrolytlösungen durchsetzt wurden, war komplexer und abhängig vom Tongehalt, dem hydraulischen Gradienten, der für die Perkolation der dispergierenden Elektrolytlösung benutzt wurde, sowie von dem Vordispergierungsgradienten, dem die Proben unterworfen wurden. Verminderung der Durchlässigkeit wurden auf die letzten Stadien der Quellung zurückgeführt, die der Dispergierung und der Porenverstopfung vorangingen. Zunahmen der Durchlässigkeit waren das Ergebnis einer Erosion dispergierter Teilchen. Proben, die vorher dem höchsten Gradienten während der Quellung unterworfen wurden, dispergierten schneller und wiesen eine stärkere Neigung zur Erosion auf. Die Wirkungen der Vordispergierungsgradienten verminderten sich mit zunehmendem Tongehalt. Es wird geschlossen, daß bei Böden, die aktive Tonminerale enthalten, sowohl auf der Zusammensetzung beruhende als auch mechanische Faktoren bei der Bestimmung der Beziehung zwischen Elektrolytkonzentration und Durchlässigkeit eine wichtige Rolle spielen.

Резюме — Для исследования эффектов разбухания глины и соотношения между проницаемостью и концентрацией электролита в почвах с малым содержанием глины, провели эксперименты со струей шлама с частицами определенных размеров, содержащих 0; 5; 7,5; 10 и 15 процентов глины (иллит натрия — фракция 2 μm). Флоккулированные образцы медленно и быстро седиментировали. После сжатия каждый образец по очереди опускали в раствор электролита, что повело (1) к разбуханию фракций глины (0,10N) и (2) к дисперсии (0,05N).

Абсолютное проникновение варьировало в зависимости от: содержания глины, процедуры седиментации, степени сжатия и концентрации электролита; однако, форма этих вариаций по отношению ко всем рассмотренным образцам была одинаковая, только разбухла глина. Увеличение гидравлического градиента выше критического значения, очевидно, слегка повышает набухание, что указывается понижением проникновения. Понижение проникновения относят к последней стадии набухания до дисперсии и до закупорки пор. Повышение проникновения приписывают эрозии диспергированных частиц. Образцы ранее, во время набухания, подвергнутых более высоким градиентам быстрее проходят дисперсию и проявляют большую тенденцию к эрозии. При более высоком содержании глины эффекты предисперсных градиентов понижаются. Решили, что как состав, так и механические факторы играют важную роль при определении отношения «концентрация электролита-проницаемость» почв, содержащих глинистые минералы.