

Influence of Salinity on Permeability Characteristics of Marine Sediments

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Abstract *Laboratory tests were conducted on compacted marine sediments to study the effect of salt concentration of permeating fluid on its permeability characteristics. Deep sea sediment samples were collected from water depths varying from 3700 to 4500 m off Mauritius coast. Liquid limit and plasticity index varied widely from 45 to 75 and 10 to 35, respectively. Permeability was found at different void ratios with distilled water and 0.2, 0.4, and 0.8 N NaCl solutions as permeating fluid. It was found that permeability increases with an increase in salt concentration for a given void ratio. This is explained by diffused double layer theory. Also, the rate of increase in permeability decreases with increase in salt concentration. The effect of salt concentration seemed to be less at higher void ratios.*

Keywords: Deep sea sediments, permeability, compaction, salinity, voids ratio, flocculation, diffused double layer theory.

Introduction

Emplacement of offshore structures and natural processes such as sediment accretion and wave-induced pressure generate pore pressures in seabed sediments. Dissipation of this pore pressure depends mainly on the permeability characteristics of the sediment. To determine ideal locations for the safe burial of hazardous materials such as radioactive wastes, a thorough knowledge of the permeability characteristics of marine sediments is essential (Bishop and Hollister 1974). Efficient utilization of dredged material for land reclamation also calls for a study of the permeability characteristics of marine sediments.

One way to study the permeability aspect in the laboratory is to compact the soil and conduct permeability tests at different void ratios. The hydraulic conductivity of compacted clay is affected by a number of factors, such as water content (Bjerrum and Huder 1980; Lambe 1958; Mitchell, Hooper, and Campanella 1965), degree of saturation (Mitchell, Hooper, and Campanella 1965; Olsen and Daniel 1981; Zimmie 1981), method of compaction (Mitchell, Hooper, and Campanella 1965), hydraulic gradient (Mitchell and Younger 1967), size of clay clods (Daniel 1984; Olson 1962), distribution of pore sizes (Gracia-Benzochea, Lovell, and Altsehaeffl 1981), chemistry of the permeating fluid (Anderson and Brown 1981; Michaels and Linn, 1954), and age of the test specimen (Dunn 1983; Mitchell, Hooper, and Campanella 1965).

The aim of this investigation is to study the effect of salinity of permeating fluid on the permeability characteristics of marine sediments.

Collection of Samples

Samples were collected from the exclusive economic zone (EEZ) of Mauritius coast (Fig. 1) using Van-veen grabs. The samples were immediately packed in polythene bags to preserve natural moisture content. Depth of water in the area varied from 3700 to 4500 m.

Preparation of Samples

Four samples (MC20, MC22, MC25, and MC30; MC stands for clay from Mauritius coast) with widely varying properties were chosen for detailed analysis. The samples were mixed with distilled water and stirred thoroughly with a mechanical stirrer. When

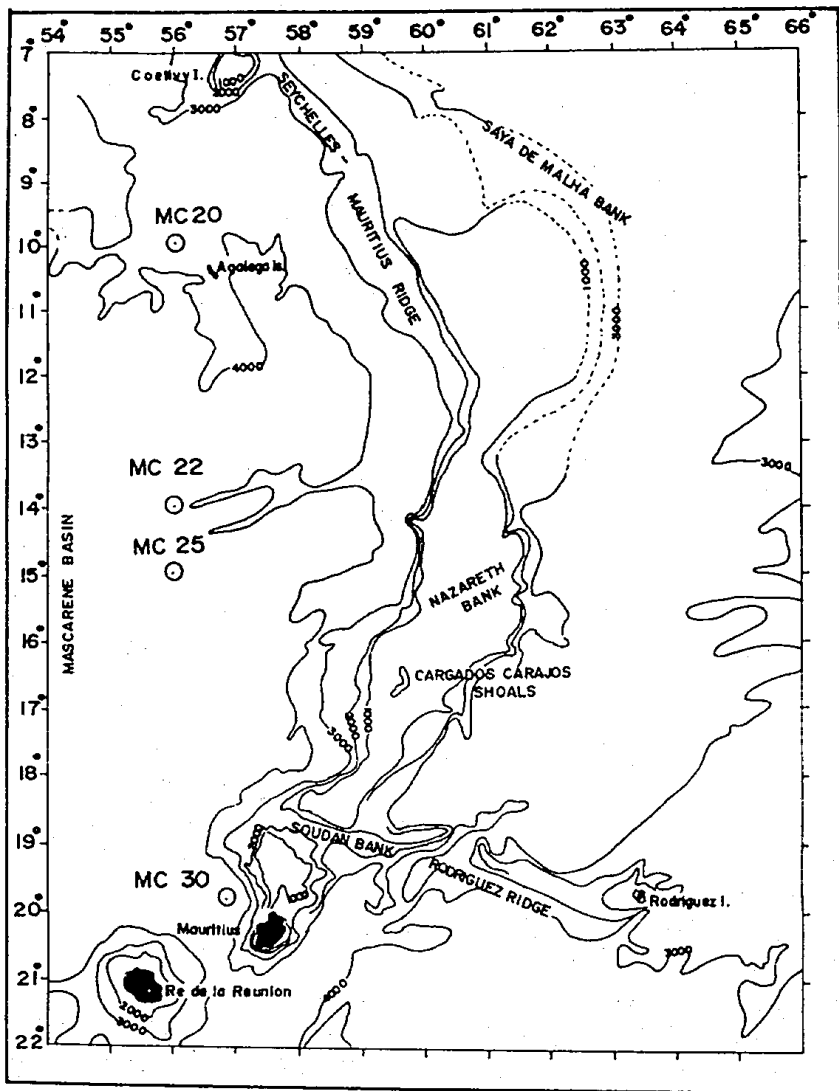


Figure 1. Location map of the EEZ of the Mauritius Coast.

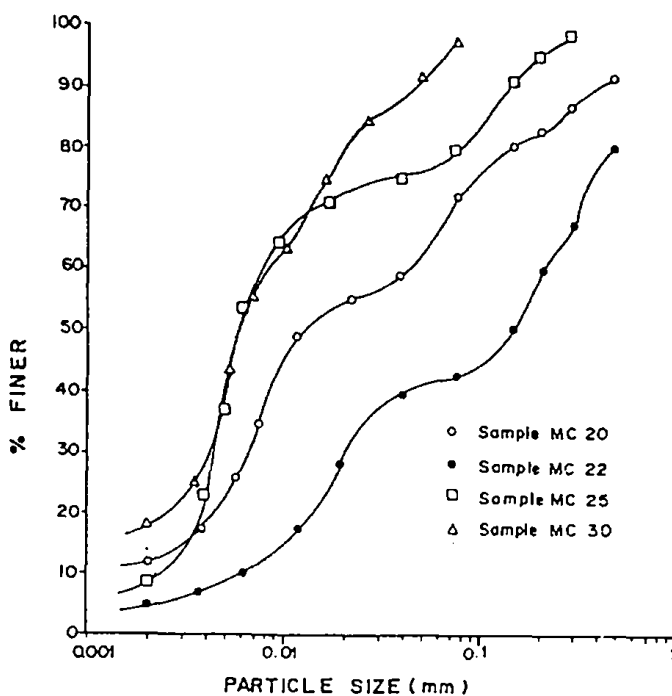


Figure 2. Grain size distribution curve.

all of the soil particles settled and clear water appeared at the top, the water was siphoned out, taking due care that no soil particle was lost. The process was repeated until salt-free water was obtained.

Grain Size Analysis

The hydrometer method was used to determine the particle size distribution of soil fractions passing through a 75-micron sieve. The soil taken for analysis was mixed with a deflocculating agent (sodium hexametaphosphate). The results from the grain-size analysis show that the main constituent of all four samples was silt. The detailed grain-size distribution is shown in Figure 2. The sand, silt, and clay contents are shown in Table 1.

Specimens were prepared without adding a dispersing agent and kept in the jar. It was found that clear water appeared in the jar within a short interval of time (about 30 min). When a deflocculating agent was added, it took more than 24 hrs for clear water to appear at the top. In the absence of the deflocculating agent, the flocs remained intact, and hence settlement of soil particles took place in a relatively shorter time. This indicates that flocs were present in the sediment.

Determination of Index Properties

Index properties were found by using soil samples prepared as described earlier. The results are shown in Table 1. In all four samples, the natural water content was more than the liquid limit. Liquid limit varied over a wide range, from 45 to 79. The plasticity index varied from 10 to 35. A-line in Figure 3 shows the relative positions of the samples. Activity of all the sediments was very high (> 1.25).

Table 1
Physical Properties of Test Soils

No.	Properties	MC20	MC22	MC25	MC30
1	Specific gravity	2.66	2.67	2.65	2.65
2	Natural moisture content	95	89	105	71
3	Liquid limit	74	45	79	63
4	Plastic limit	43	35	49	28
5	Plasticity index	31	10	30	35
6	Grain size distributions				
	Clay size, $< 2 \mu$ (%)	12	5	9	18
	Silt size $> 2 \mu$ & $< 75 \mu$ (%)	61	38	71	80
	Sand size, $> 75 \mu$ (%)	27	55	20	2
7	Activity ^a	2.6	2.0	3.3	1.9

^aActivity of clay = plasticity index/% by weight finer than 2μ .

Compaction and Permeability

Compaction was done by a standard proctor apparatus using distilled water. At a particular void ratio after compaction, the sample was kept for saturation in distilled water. At a particular void ratio after compaction, the sample was kept for saturation in distilled water by applying back pressure. After saturation, a falling head permeability test was conducted in the same Proctor's mold by using distilled water as the permeating fluid. The aim of the study was to investigate the effect of salt concentration of the permeating

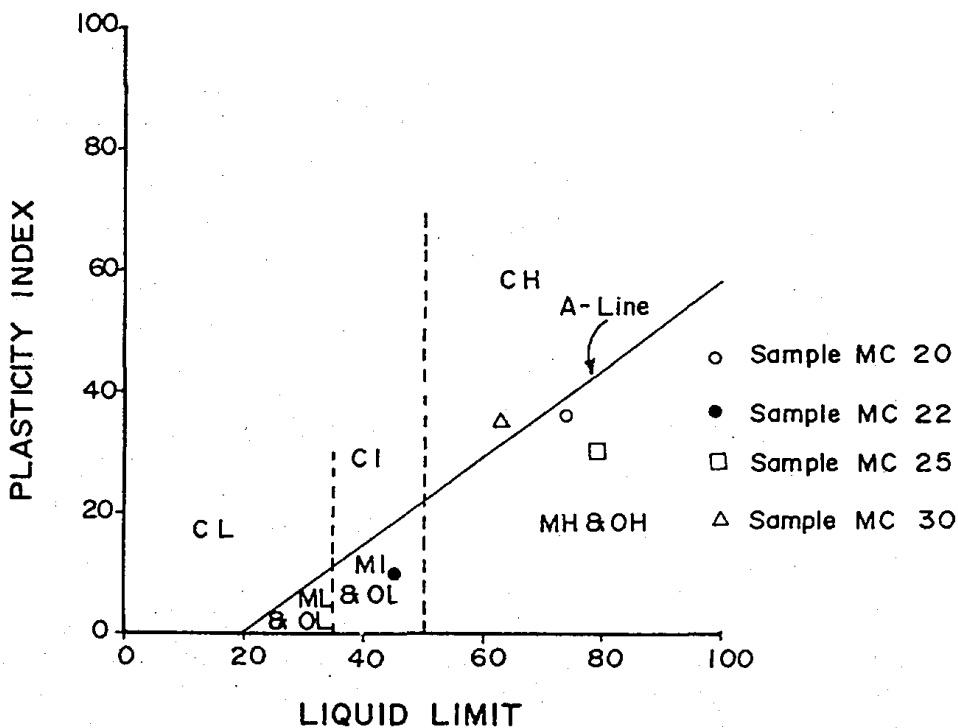


Figure 3. Liquid limit versus plasticity index.

fluid on permeability characteristics. Hence, the void ratio was held constant, and the salt concentration of the permeating fluid was varied. At a given void ratio, permeability was first found by using distilled water and then by successively using 0.2, 0.4, and 0.8 N sodium chloride solutions. Each time, the sample was saturated by the particular normal solution by applying back pressure, and permeability was found.

Compaction was done at different water contents using distilled water, and permeability was found at each void ratio by using distilled water and different normal solutions, as explained earlier. Compaction curves and corresponding permeability test results are shown in Figure 4.

Results and Discussion

From the results it can be observed that for a given void ratio, permeability increases with increase in salt concentration of the permeating fluid (Fig. 4). The permeability coefficient for distilled water was found to be lowest. The effect of salt concentration on permeability was least in the case of sample MC22, which had the lowest clay content, and the effect was highest in MC30, which had the highest clay content. This phenomenon is explained by diffused double layer theory.

It has been fairly well established (Scott 1963 and others) that the behavior of coarse-grained soils is predominantly governed by gravitational and mechanical forces, whereas in the case of fine-grained soils, because of large surface areas and associated physicochemical factors, effects of surface forces are predominant. Because of the presence of clay minerals in the fine-grained soils, a net negative charge is always found to

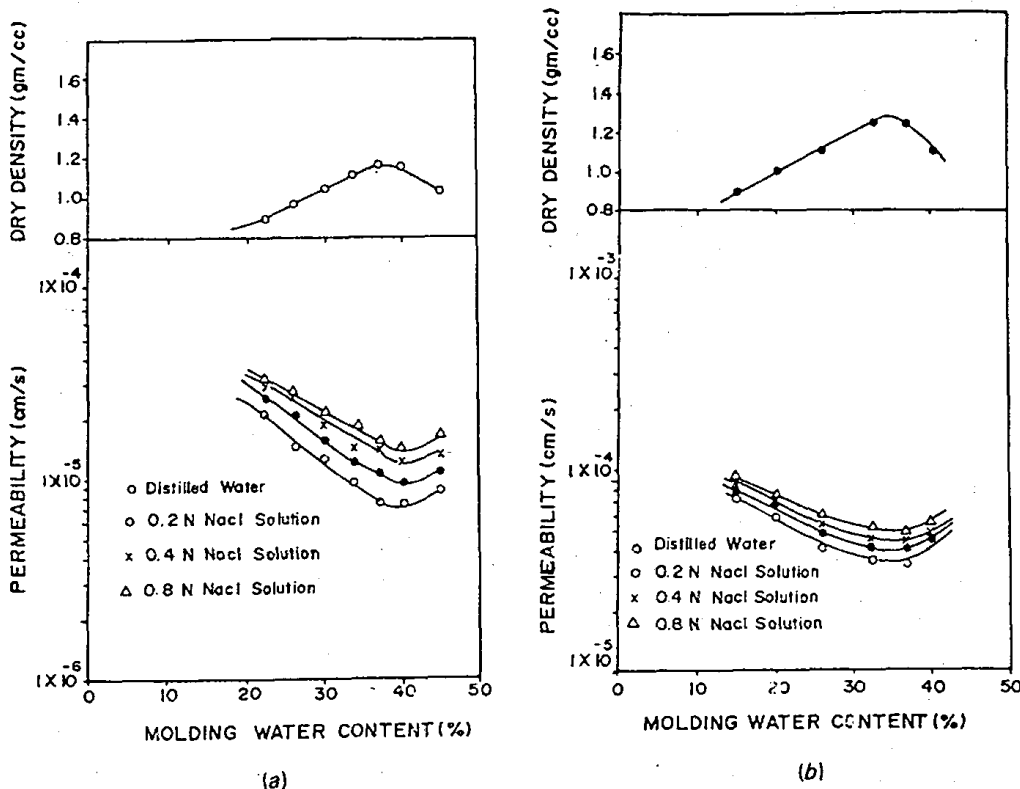


Figure 4. (a) Permeability and dry density versus molding waer content for sample MC20. (b) Permeability and dry density versus molding water content for sample MC22.

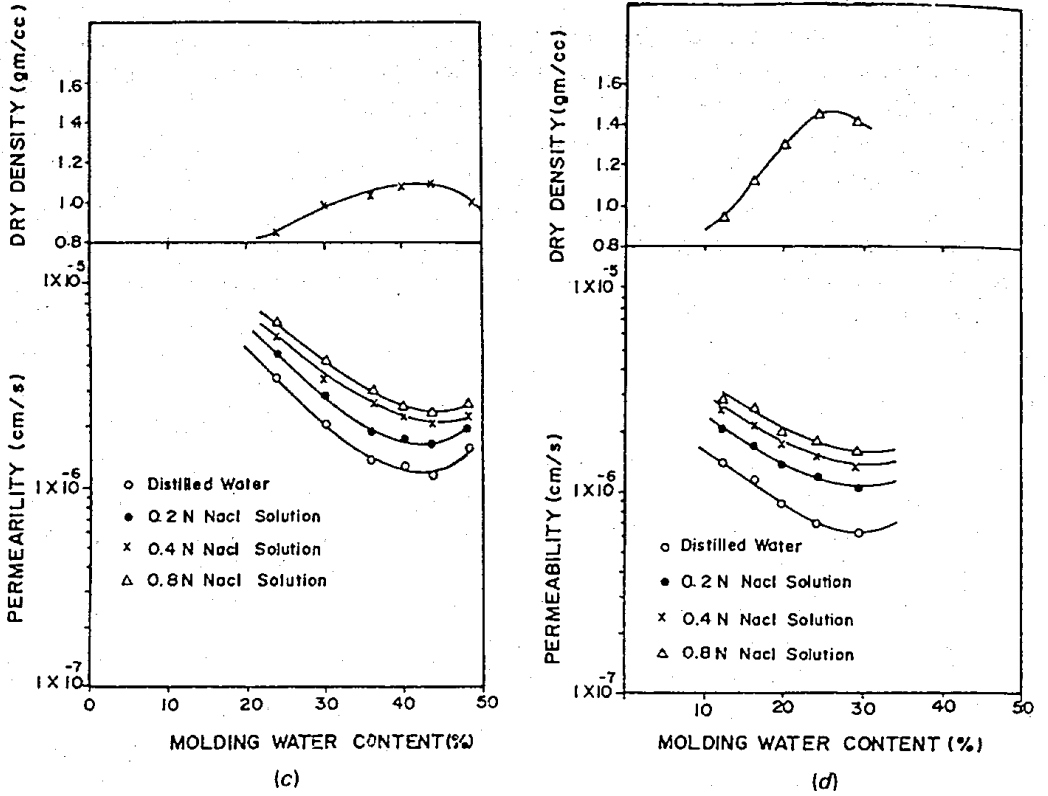


Figure 4 (Continued). (c) Permeability and dry density versus molding waer content for sample MC25. (d) Permeability and dry density versus molding water content for sample MC30.

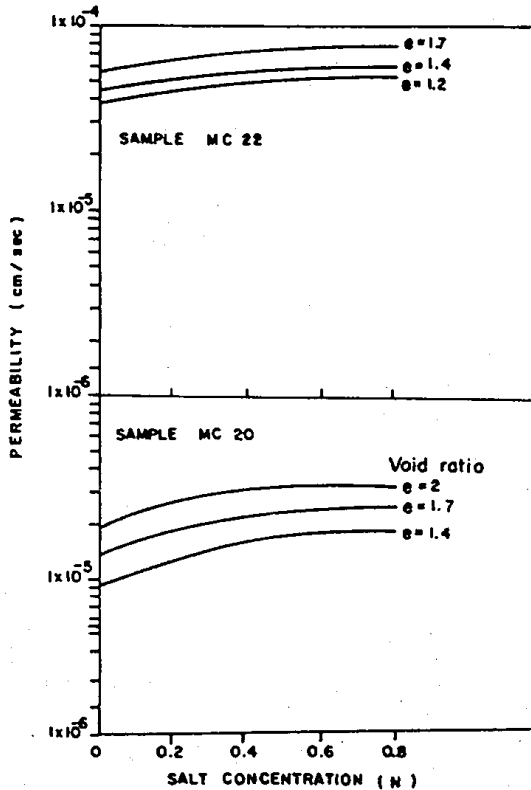
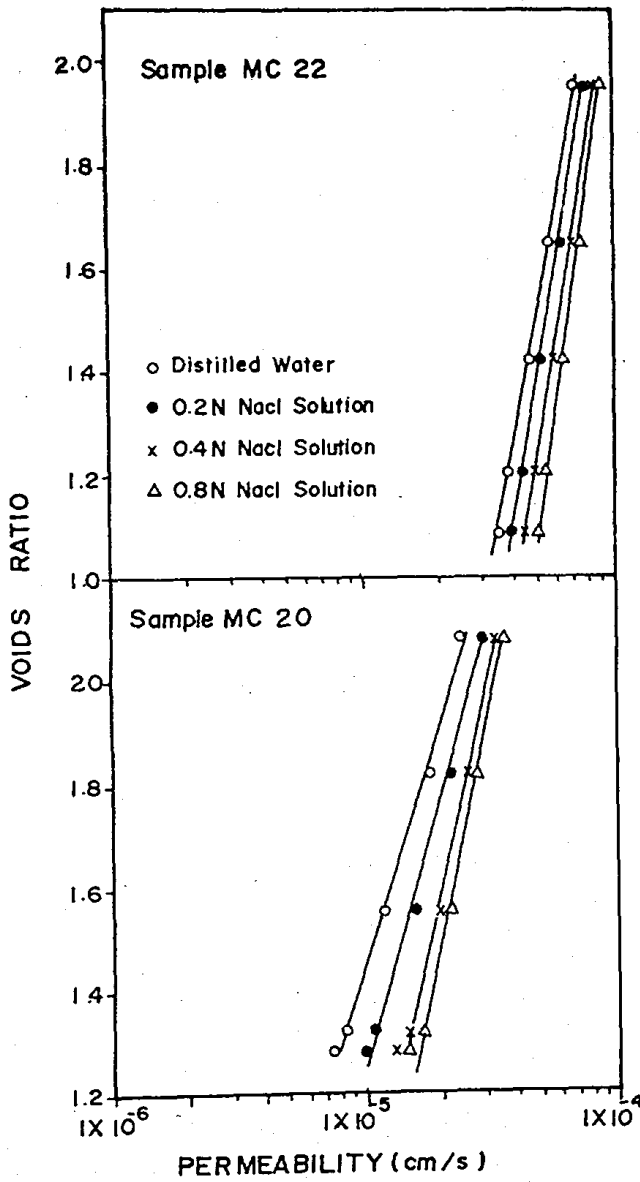


Figure 5. Salt concentration versus permeability for samples MC20 and MC22.

exist on the surface of the soil colloid. This negative charge is neutralized by ions present in water, which swarm around the colloid to form a diffused double layer. The two advancing soil particles begin to repel each other when their double layers come into contact. The repulsive force between the adjacent particles for any given spacing is therefore directly related to the sizes of the double layers on the two particles, and any change in the characteristics of the soil-water system that reduces the thickness of the double layer reduces this repulsive force and the tendency toward flocculation increases. Hence, the interparticle interaction forces in a clay-water-electrolyte system are influenced by the properties of both the clay mineral and the pore fluid. An increase in electrolyte concentration is found to depress the double layer, and therefore more floccu-



(a)

Figure 6. (a) Void ratio versus permeability for samples MC20 and MC22.

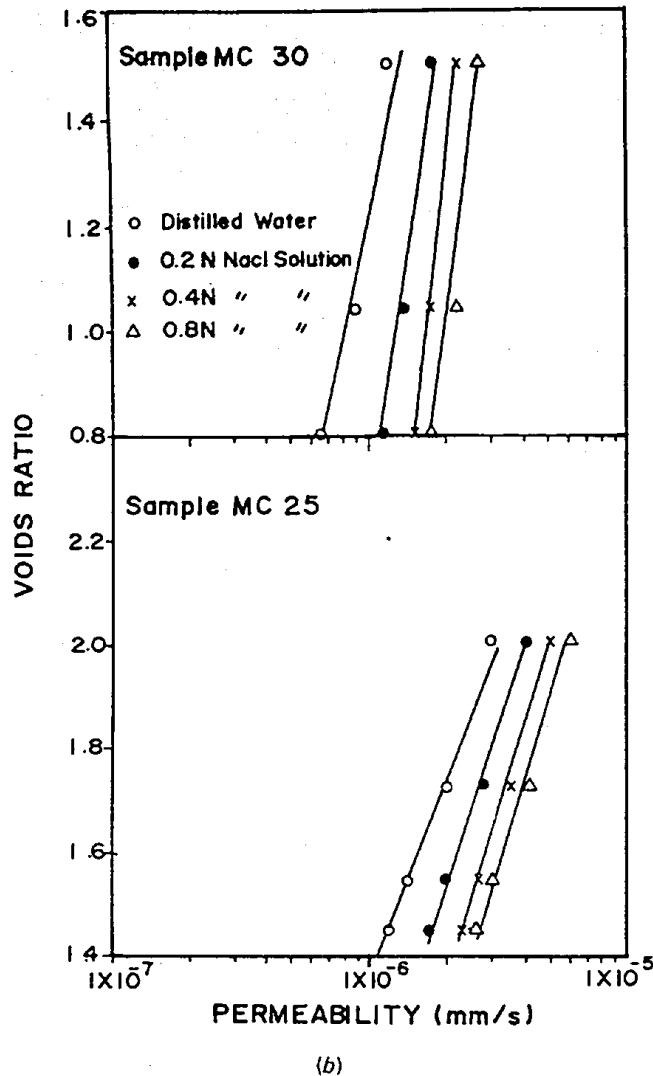


Figure 6 (Continued). (b) Void ratio versus permeability for samples MC25 and MC30.

lation occurs. The increase in permeability with the increase in salt concentration can be attributed to this reaction.

The second observation that can be made is that the rate of increase in permeability decreases with an increase in salt concentration (Fig. 5). At a given void ratio, the plot of permeability versus salt concentration has been drawn for the two samples MC20 and MC22. A similar observation also can be made for the other samples. It can be seen that permeability tends to become asymptotic along the x-axis, meaning that a further increase in salt concentration will not bring about an increase in permeability. An increase in salt concentration of the permeant increases the tendency to flocculation. But the degree of flocculation cannot increase indefinitely, and there should be a limit at which the disorder of the particles is maximum; beyond this limit, an increase in salt concentration would not affect the permeability. Thus, permeability is more sensitive to change in salt concentration only at low-level concentrations for the sediments tested in this study.

Finally, the log K versus e curves (Fig. 6) are seen to converge at a higher void ratio, and the effect is found to be maximum near the maximum dry density or minimum

void ratio point. A possible explanation for this could be as follows. At a higher void ratio, the interparticle distance is relatively large, and hence the effect of flocculation due to the diffused double layer becomes less significant. In other words, at this stage it is the higher void ratio that governs the magnitude of permeability rather than the effect of flocculation due to diffused double layer. On the other hand, at a lower void ratio, the interparticle distance is relatively low, and the effect of flocculation becomes more significant.

Conclusions

The following conclusions were drawn from the test results.

- (1) Hydrometer analysis with and without dispersing agent indicates the presence of flocs in the sediment.
- (2) Permeability increases with increases in salt concentration of the permeating fluid for a given void ratio.
- (3) The rate of increase of permeability decreases with increases in salt concentration.
- (4) The effect of salt concentration is relatively low at higher void ratios and maximum near minimum void ratios.
- (5) The influence of salt concentration is greater in samples with higher clay content.

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