Sodium and Calcium Salts Impact on Soil Permeability

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Abstract

The study investigated the effect of two inorganic salts namely sodium chloride NaCl and calcium sulphate $CaSO_4$ on subsoils permeability. Two subsoils designated as A and B were taken from two borrow pits in Ibadan south-western Nigeria. The subsoils were contaminated with four concentrations of each salt 10, 30, 50 and 70 g/dm. The subsoils coefficients of permeability were monitored for about 364 days. The results revealed that NaCl led to increase in soil permeability while $CaSO_4$ brought about reduction in soil coefficient of permeability. The reduction in soil permeability by $CaSO_4$ was due to strong bond formed when Ca^{2+} is attracted to soil adsorbed layers while Na^+ formed weak bond if attracted to adsorbed layer.

Keywords: Inorganic salt, Subsoils, coefficient of permeability, soil contamination

1 Introduction

Soil encountered in civil engineering discipline can be divided into two groups namely: coarse or frictional soil and fine or cohesive soil. The majority of soils seen at various construction sites are mixture of both fine and coarse grained soils. With the aid of sieves and hydrometer, they can be separated into individual particle sizes. The soils comprise mixture of inorganic mineral particles together with void made of air and water depending of their degree of saturation. The elements in soil can be divided into groups. The first group includes silicon Si and Oxygen O. The second group comprises elements such as aluminium Al, iron Fe, calcium Ca, magnesium Mg, potassium K, sodium Na and carbon C. These two groups represent the macro–elements. Tin Ti, manganese Mn, nitrogen N, phosphorus P, sulphur S and hydrogen H form the third group (Bohr, et al, 1979).

The initial phase of soil i.e. solid, liquid and gas has changed due to presence of foreign materials such as contaminants. As such, the void is now occupied by air, water and contaminants. A few contaminants ions are adsorbed on the surface of soil particles. The rest are either absorbed by soil grains or infiltrated into the soil below and eventually end up in groundwater. The contaminants are result of improper management of urban

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waste materials due to changes in industrial practices which took placed at the beginning of eighteen century in advanced worlds and twentieth century in developing countries.

Sources of contaminants into soils can be traced to the following operations within the environment in developed and developing countries. Ocean surge caused occasional flooding of coastal area with salt water. This action would lead to addition of salt minerals into soil. At many places, sites have been associated with mining, smelting and manufacturing of metals. Where mining has taken place, metallic elements will be present in the soil in greater amounts (Davies, 1971, Davies and Roberts, 1978; Webb et al, 1978). However, ore concentration and smelting will result in further contamination of the environment and soils. The wastes from chemical industries are found littering both urban and rural soils due to improper management system. The manufacturing of pesticides, including insecticides, fungicides and herbicides may lead to dangerous levels of chemical wastes in the soils. The sites of former scrap yards are proving to be some of the most highly polluted soils of urban areas associated with residue of metals, asbestos, oils and other substances which are phytoxic, a danger to human health or aggressive to building structures (Bridges, 1987). Although the bulk of domestic waste deposited in landfill is innocuous, it does contain significant quantities of toxic elements that are soluble and mobile. All designs for cover systems incorporate a barrier layer, such as clay, limestone, gravel and plastic to prevent leachate from polluting the soils beneath are not absolute. The cover system will surely break either when the landfill is in operation or in distant future (Pfeffer, 1992).

It is evident that changes in the chemical nature of the soil brought about by the addition of pollutants may present a hazard to construction works. Furthermore, it may lead to adverse interactions with building materials, toxicity to soil flora and fauna and also have direct effects on soil properties. Yanful (1982) reported increase in hydraulic conductivity of approximately two orders of magnitude for samples of glacial clays from Ontario permeated with brine. Ho (1985) presented data on the effects of NaCl brine on the grain-size curve for Indian Head till and Regina clay. He found no significant change in grain size between water samples and samples prepared with NaCl brine. Barbour and Fredlund (1989) and Maio (1996) have shown that on exposure to concentrated salt solutions, volume changes of saturated clay soils also occurred from fluid flow out of the clay in response to chemical concentration gradients.

Ikejir and Tanimoto (1993) showed that the effect of cation was very little in tan φ. Clays show depending on their mineralogy, considerable changes in properties when exposed to salt solutions. The impact of changes in net interparticle electrical forces from variations in initial pore-water salt concentration on the swell and compressibility behaviour of clay soils was well documented (Mitchell, 1993; Rao and Reddy, 1998). Muntohar and Hantoro (2002) worked on the effects of the engineering properties of clayey soils when blended with lime and rice husk ask. The results confirmed that the blend would diminish swell behaviour of clayey soils with increasing in plasticity index, California bearing ratio CBR, angle of friction, soil cohesion. The liquid limit of a Na-saturated sample for Bangkok-clay increased with increasing NaCl concentration and when substituting Ca for Na in a similar manner to Ariake clay, but the extent of the liquid limit change by such treatments was much smaller for Bangkok clay than for Ariake clay (Ohtsubo et al, 2003).

Sivapullaiah et al (2000) investigated the strength behaviour of lime-treated montmorillonitic natural black cotton soil in the presence of varying sulphate contents after curing for periods of up to 365 days. The result showed reduction in shear strength

due to a reduction in effective cohesion intercepts occurs for lime-treated soil cured with sulphate for long periods.   Using four different clays and three chloride salts (NaCl, KCl and CaCl$_2$), Schmitz and van Paasen (2003) reported decaying in the liquid limit as salt molarity increased. Song et al (2003) investigated geotechnical properties of solid waste soils sampled from reclaimed landfill site for use as sub base materials.   The tests showed that geotechnical properties are clearly affected by the magnitude of organic matter content.   As the organic matter content increases, the maximum dry unit weight, the shear strength and bearing capacity of ground decrease, while the void ratio and compressibility increase.   Lee et al (2005) also investigated the effect of CaCl$_2$ solutions with concentration of 5, 10, 20, 50, 100, and 500 mM on the liquid limits of geosynthesis clay liners (GCLs).

Sivapullaiah and Manju (2005) investigated geotechnical properties of a low plasticity soil (wL= 38%) using NaOH solution.   They reported that the liquid limit of the test soil increased with increasing NaOH concentration due to the forming of new swelling compounds.   Arasan and Yetimoglu (2008) used salt solution in-place of distil water for determination of clay soils liquid and plastic limits.   The results showed that increase in the salts (copper sulphate, iron sulphate and potassium chloride) led to increase in CL-clay liquid and plastic limits.

The above literature revealed that addition of inorganic salts to soils has both positive and negative influence on soil geotechnical properties.   Nearly all aspects of soil geotechnical properties influenced by contaminants with little works on effect of salts on sub soil permeability have been reported.   The present study focused on inorganic salts impact on soil permeability.

2   Materials and Method

Soil samples for the experimental study were taken from two burrow pits in Ibadan South-western Nigeria.   At the burrow pits, the top soils were removed up to 1m depth before enough quantity of subsoils (soil samples) was taken to laboratory.   In the laboratory, each subsoil was placed on flat platform and mixed thoroughly to obtain homogeneous sample as shown in Figure 1.   Sixty four plastic containers with bottom perforated were procured.   Aside controls, each subsoil was subdivided into thirty two soil samples and grouped into eight.   Each group has four soil samples.   In order to ensure even density for soil sample, each container was filled with soil in six layers with each layer of about 30kg receiving 62 strokes of wooden pestle from equal height.   The soil samples groups named for subsoil A were A1, A2, A3, A4, A5, A6, A7 and A8 while those of subsoil B were B1, B2, B3, B4, B5, B6, B7 and B8. The right quantities of the inorganic salts sodium chloride (NaCl) and calcium sulphate (CaSO4) were dissolved in determined quantity of distilled water to produced 10, 30, 50 and 70g/dm^3 concentrations.   The prepared inorganic salts concentrations were applied by gravity to soil samples as shown in Figure 2.   During the salts solution application, each soil sample received single dose of salt concentration of 18 dm^3.   Soil samples with labels A1, A2, A3, A4, B1, B2, B3 and B4 were contaminated with single dosage of NaCl salt solution while the rest were contaminated with CaSO$_4$ salt solution.

The particle size analysis, Atterberg limits and coefficient of permeability adopting variable falling head method were determined for the two subsoils in accordance with BS 1377 (1998).   The contaminated soil samples coefficient of permeability (CP) was

determined on day 7, 14, 21, 28, 56 112, 196, 286 and 364.   An appropriate soil sample was taken from each container and sundried as shown in Figure 3.   The soil sample was sieved with sieve no 4 (4.75mm aperture).   The soil retained on the sieve was disposed of and the filtered soil coefficient of permeability was determined using variable head method as detailed in BS 1377 (1998).

Figure 1: Mixing of subsoil for uniformity

Figure 2: Application of salt solution to soil sample by gravity

Figure 3: Drying of soil sample prior to permeability test

3   Results and Discussion

Subsoils A and B grading curves are shown in Figures 4 and 5. Also, their liquid and plastic limits were 36%, 22% and 42%, 19.6% respectively. In line with Unified Soil Classification System (UCSC) the two subsois were found to be SP-SC. They were well graded and soil A was more blended than soil B. The subsoils A and B coefficient of permeability were 5.688 x 10-6 and 5.243 x 10-6 mm/s. respectively. These values are for uncontaminated subsoils.

The coefficients of permeability of NaCl and $CaSO_4$ contaminated soil samples were measured from day 7 to day 364 after the application of salt solutions and shown in Tables 1 and 2. The trend observed for the two subsoils contaminated with different concentrations of NaCl solutions was very similar. The values of CP increased as concentrations of NaCl increased and also with duration of contamination. The coefficient of permeability values of soil samples A increased from 5.688 x 10-6 mm/s to 9.462 x 10-6 mm/s while those of samples B increased from 5.243 x 10-6 mm/s to 9.612 x 10-6 mm/s. The result was in agreement with the outcome of the work of Yanful (1982).

When NaCl salt dissolved in water, it dissociated into cation and anion. The cations carried positive electrical charges while anions negative charges. The cations are exchangeable and as such Ca^{2+}, Mg^{2+}, K^+, Na^+ and H^+ are the dominant exchangeable cations. When divalent cations are absorbed in soil adsorbed layers, they form strong bond due to divalency nature and if such divalent cation is replaced with monovalent cation weaker bond is produced. Consequently, Na^+ is a monovalent cation and when attracted to the adsorbed layers of soil (clay), it produces weaker bond that constitutes least resistance to passage of water. Thus, the soil coefficient of permeability will be increased. Soil samples A and B contaminated with $CaSO_4$ experienced reduction in coefficient of permeability. For instance, soil samples B coefficient of permeability (CP) reduced from 5.243 x 10-6 mm/s to 2.359 x 10-6 mm/s. The reduction observed in CP is as a result of attraction of Ca^{2+} to the adsorbed layers produced strong bond that would be hard to break and high resistance to the passage of water. This bond is responsible for reduction in CP obtained for the two soils.
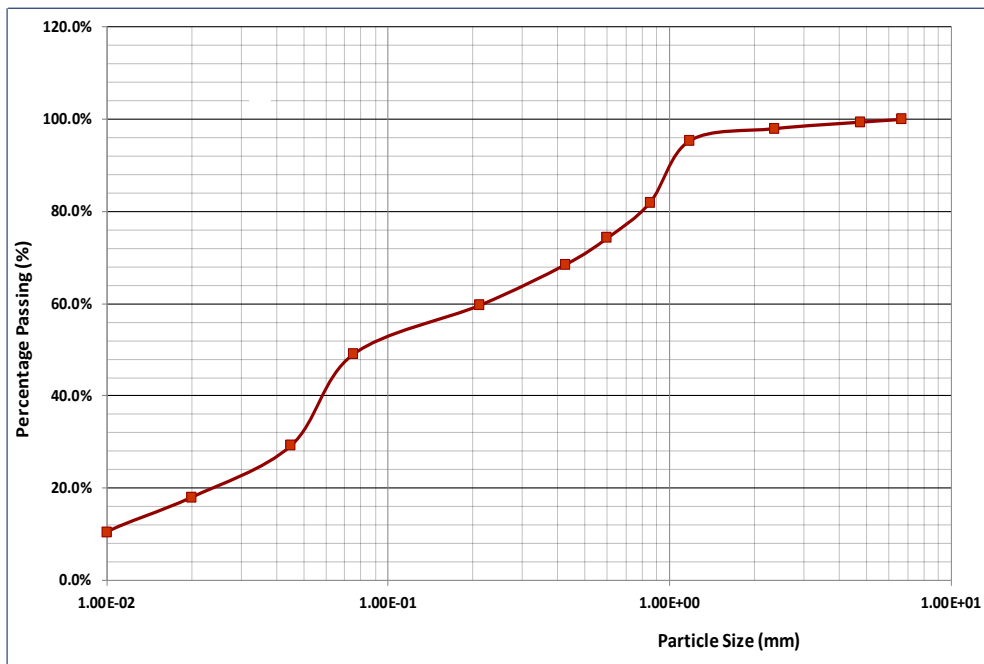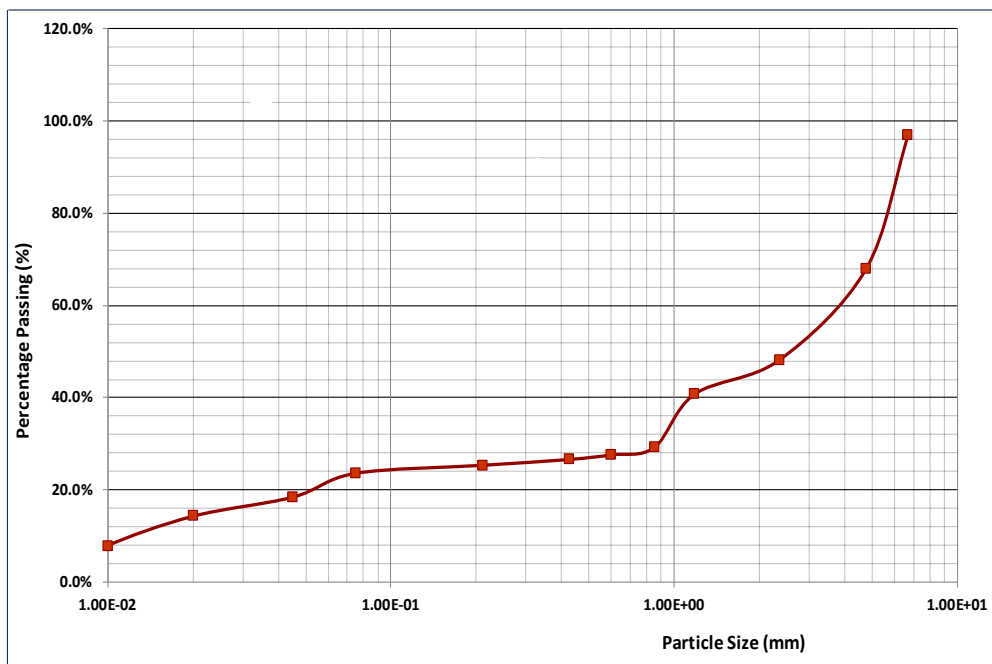
Figure 4: Grading curve of subsoil A

Figure 5: Grading curve of Subsoil B

Table 1: Coefficient of permeability values of contaminated soil samples of A

Testing	coefficient of permeability (x 10^{-6}) mm/s							
day	NaCl contaminated soil samples				CaSO$_4$ contaminated soil samples			
	B1	B2	B3	B4	B5	B6	B7	B8
7	5.989	6.016	6.016	6.016	5.551	5.497	5.387	5.196
14	6.153	6.180	6.317	6.290	5.196	5.059	4.977	4.813
28	6.563	6.563	6.618	6.837	4.704	4.649	4.649	4.485
56	6.837	7.110	7.466	7.657	4.430	4.266	4.184	4.075
112	7.657	7.876	8.012	8.204	3.965	3.965	3.719	3.664
196	8.204	8.751	9.079	9.024	3.828	3.664	3.390	3.117
280	8.587	8.970	9.243	9.298	3.719	3.610	3.336	3.008
364	8.751	9.024	9.298	9.462	3.664	3.555	3.282	2.953

Uncontaminated soil sample A coefficient of permeability is 5.688 x 10^{-6} mm/s

Table2: Coefficient of permeability values contaminated soil samples B

Testing	coefficient of permeability (x 10^{-6}) mm/s							
day	NaCl contaminated soil samples				CaSO$_4$ contaminated soil samples			
	A1	A2	A3	A4	A5	A6	A7	A8
7	5.534	5.534	5.534	5.826	4.952	4.952	4.952	4.660
14	5.534	5.826	5.826	5.826	4.660	4.660	4.370	4.370
28	6.117	6.117	6.117	6.408	4.079	4.079	4.079	3.787
56	6.408	6.699	6.991	7.282	3.495	3.787	3.554	3.495
112	7.282	7.573	7.573	7.865	3.495	3.495	3.204	3.204
196	8.156	8.447	8.738	8.738	2.913	2.825	2.767	2.767
280	8.447	8.447	9.321	9.612	2.913	2.651	2.563	2.418
364	8.447	8.738	9.321	9.612	2.796	2.563	2.505	2.359

Uncontaminated soil sample A coefficient of permeability is 5.243 x10^{-6} mm/s

4   Conclusion

At the end of the experimental study, the coefficient of permeability of subsoils A and B increased as a result of addition of NaCl salt with time and with increasing in concentration. The two soils coefficient of permeability reduced with increasing CaSO$_4$ concentration and time.The reduction in coefficient of permeability due to addition of CaSO$_4$ was as a result of attraction of Ca^{2+} divalent cation to adsorbed layers of soil to produce strong bond. This bond would constitute resistance to passage of water in soil. On the other hand the increase in coefficient of permeability observed for NaCl contaminated soils was due to weak bond produced when monovalent cation like Na$^+$ is attracted to adsorbed layer.

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