Influence of Sodium Chloride on Subgrade Soil California Bearing Ratio.

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ABSTRACT

The effect of sodium chloride on subgrade soil was investigated. Twenty subgrade soil samples stored in plastic containers were subjected to differing concentrations of NaCl for 364 days. They were tested for exchangeable sodium Na^+, chloride Cl^-, cation exchange capacity (CEC), and California Bearing Ratio (CBR). The results showed that CBR values decreased with increase in the Na^+, Cl^- and CEC values. The model developed revealed that soil CBR improved with time. The time was function of Na^+, Cl^- and CEC magnitudes.

(Keywords: cation exchange capacity, CEC, California bearing ration, CBR, soil, subgrade, salt)

INTRODUCTION

The California bearing ratio (CBR) test is a penetration test for evaluation of the strength of road subgrade developed by the California State Department of Transportation. The test is best done by measuring the force required to penetrate a soil sample with a plunger of standard area. The measured force is then divided by the force required to achieve an equal penetration on a standard crushed rock material. The stronger the subgrade CBR the less will be the thickness of the road elements, this gives a considerable cost saving. Conversely, if CBR of the subgrade is small, the road elements would be thicker to spread the wheel load over a greater area of the weak subgrade in order that the weak subgrade material is not deformed resulting to road failure.

The initial compositions of soil air, water and soil solid have changed overtime due to some human and natural activities. These activities have introduced contaminants into soils. Few existing works showed that soils compositions have changed due to addition of pollutants. Nakano and Miyauchi (1996) concluded that the levels of available phosphorus P, exchangeable calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) were lowest during fallow period in Sweden soil. Miko et al. (2003) carried out extensive study on soils from Croatia and Slovakia and opined that soils in the Croatian Karst were enriched in nickel (Ni), manganese (Mn), and copper (Cu) while soils from the Slovak Karst had high lead (Pb) and zinc (Zn) concentrations. Using two main tests; physicio-chemical and batch equilibrium to investigate sorption capacity of five clay soils from South Wales in the United Kingdom, Wan Zuhairi (2003) concluded that the maximum sorption capacities are highly influenced by the chemical properties of the soils.

Furthermore, Romic and Romic (2003) studied the distribution of heavy metals in agricultural topsoils in urban area; concluded that the variations in concentrations of the investigated elements are thus of both natural and anthropogenic origin. A similar study was done by Thuy et al. (2000) in Danang-Hoian area (Vietnam) where Cu, Ni, and Zn showed significant effects in most of the cultivated soil categories, especially in the industrial soils. In a study carried out at Osogbo, Fakayode and Olu-Owolabi (2003) found that the levels of metals such as Pb, Ca, Cu, Ni and Zn at the motor parks and mechanic workshops were far above the levels at the normal natural sites. A study carried out by Prahargaj et al. (2003) on the topsoil around ash pond revealed that the topsoil contained among others high levels of Pb, Zn, Cu, Ni, and Mn. The levels of metals such as Pb, Cu, Zn, Ni, and Mn in soils and plants around Ikeja Estate were found to be significantly higher than the background concentrations at remote control sites (Fakayode and Onianwa, 2002).

Evidences are emerging with respect to the effect of contaminants on soil properties. 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. The effect of ageing on the strength and compressibility of calcalreous desert sand at Kuwait City was examined by Al-Sanad and Ismael (1996). The results indicated an increase in the shear strength and a reduction in compressibility at a decreasing rate with time as a result of particle interlocking, reorientation and dispersion and increased in friction at a constant effective stress. Panadian and Krishna (2001) carried out an experimental study to understand the effect of murrum addition on the CBR of fly ash both for soaked and unsoaked conditions. The study revealed that addition of murrum increased the CBR of fly ash significantly. Schmitz and Paasen (2003) reported decaying in the liquid limit as salt molarity increased. 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 to Ariake clay (Ohtsubo et al. 2000).

The practice of using salt for de-icing activities is one of numerous ways of introducing contaminants into soil. Dryland salinity has not only devastating impacts on agricultural lands and natural ecosystems, but also affects regional towns and transportation infrastructure. More than 80 percent of regional towns and cities in Australia have ongoing costs related to the damage caused by salinity (both irrigation and dryland) to existing infrastructure (McRobert and Robinson, 2000).

The damage to roads incurred from salts depends upon the type of salt and concentration present, which varies with local climate and geology. Each type of salt has different solubility and crystallization properties. Only water soluble salts are able to move through the road structure and, if evaporation occurs, these salt concentrate and may become solid, resulting in deformities (NSW Agriculture, 2003; Kodikara and Sierakowski, 2004). It is difficult to accurately cost the impact of salinity on roads as it is complicated to separate salinity damage from damage caused by other factors, such as poor construction or increased traffic loading. Costs can be incurred at a number of different stages including construction, ongoing repair and maintenance, and reduced lifespan. Several reports have estimated the costs associated with dryland salinity damage on roads (Wilson, 1999; Dames and Moore, 2001; Hajkowicz, 2002; NSW Agriculture, 2003). Most urban cities located near seas are facing with problem of sea water overflow. Consequently, the study focus on the effect of sodium chloride one of the components of sea water on subgrade soil CBR.

MATERIALS AND METHODS

Twenty subgrade soil samples were obtained at a borrow pit located along Ajibode road in Ibadan, Nigeria. In addition, enough quantity of sodium chloride, distilled water, and twenty 120-liter plastic containers with bottom perforated were procured. A portion of the subgrade soil was set aside as control sample at the collection site. The subgrade soil sample was stored in the 120-liter plastic containers with an overboard of 20 liters occupied with salt solution. Altogether, each plastic container received 180 kg of subgrade soil sample. The right quantities of sodium chloride (NaCl) were diluted with required amount of distilled water to produce 10, 30, 50 and 70g/dm^3 concentrated salt solutions. The plastic containers with soil were divided into four groups namely: A1, A2, A3, and A4. Soil samples in group A1 received 18 liters each of 10 g/l of NaCl solution: those in group A2 received 18 liters of 30g/l of NaCl and so on as shown in Figure 1.

The dosed soil samples were stored in open-aired shed for a period of 364 days covering the tests duration. The soil properties monitored were cation exchange capacity (CEC), exchangeable cation Na^+, exchangeable anion Cl^- and CBR. The tests were performed on the contaminated soil samples on day 7, 14, 28, 56, 112, 196, 280, and 364. Prior to the geotechnical and chemical tests, suitable quantity of soil was taken from each of the containers and air-dried.

The soil samples chemical properties determinations were carried out in accordance with the recommended soil chemical test procedures by Agricultural Experiment Stations of North Central Region of United State of America (1998). The precise determination of CEC is time consuming. Soil test laboratories in the North Centre Region of United States of America have shown that estimation of CEC by summation of exchangeable K, Ca, Na and Mg is acceptable for most soils. In Michigan, Warncke et al. (1980) found that CEC by summation is a good estimate of the actual CEC in acid, neutral and calcareous soils. Consequently, the CEC for subsoils and soil samples were determined by summing the exchangeable K^+, Ca^{++}, Na^+ and Mg^{++}. Sodium availability in soil is generally estimated by measurement of the water soluble and exchangeable forms. The amount of Na^+ in the soil solution is quite small relative to the amount in the exchangeable form. Hence the quantity of Na cation extracted in most soil test procedure is simply referred to as exchangeable Na^+ (Warncke and Brown, 1998).

Figure 1: Application of Sodium Chloride to the Soil Sample in the Containers.

Mercury (ii) thiocyanate method was adopted during the determination of exchangeable Cl^- ion levels in both control and contaminated soil samples.

Prior to soil sample CBR determination, the particle size analysis and optimum moisture content (OMC) of the soil were determined in accordance with BS 1377 (1991). The compaction test yielded soil sample OMC. The OMC values were used to prepare samples for CBR test. The Compaction and unsoaked CBR tests were conducted in accordance with BS 1377 (1991). About 5.5kg of 4.75mm maximum size was taken from soil sample air dried and prepared to the desired optimum moisture content of the soil. The weight of the mould less base plate and collar was taken. The mould was properly set up with base plate and spacer disk put in place.

The moist soil sample was compacted in 3 layers with each receiving 62 blows in the mould. The collar was removed from the mould; the specimen was trimmed, smoothened and flushed with the mould. Holes formed were patched. The base plate and spacer disk were removed, the weight of mould plus compacted soil was taken and the wet soil weight determined. A piece of filter paper was placed each on the base plate, the specimen inverted so that the soil was in contact with the filter paper on the base.

Sufficient weights not less than 4.5kg were placed on the sample to stimulate the required overburden pressure. The specimen was placed in the compression machine with piston not greater than 4.5kg. The load and penetration dials were reset to zero. Penetration testing was accomplished in a compression machine using a strain of 1.27mm/min. Readings of loads versus penetration were taken at each 0.5mm of penetration to include the value of 5.0mm, and then at each 2.5mm increment thereafter until the total penetration was 12.5mm. The specimen was extruded and three representative water content samples were taken. The readings taken were used in estimating soil sample CBR.

The CBR, Na^+, Cl^-, and CEC data obtained were used to develop predictive model for determination of CBR at given time. The model was developed to predict the value of CBR at constant magnitudes of CEC, Na^+ and Cl^- at a given time. During the development of the mode, multiple linear regression analytical package was used. The independent variables were CEC, Na^+, Cl^- and time while the only dependent variable was CBR. The multiple regression analysis yielded the equation below:

$$CBR_t = 10.68 + 8.643 \times 10^{-5} \Delta t - 0.432 \Delta CEC + 3.863 \times 10^{-2} \Delta Na^+ - 1.30 \times 10^{-4} \Delta Cl^-$$

Where:
CBR_t is the CBR at time t in years,
Δt is the forecasting years
ΔCEC is difference between the expected CEC and CEC of uncontaminated soil sample,
ΔNa^+ is the difference between the expected Na^+_t and Na^+ of uncontaminated soil sample,

ΔCl^- is the difference between the expected Cl^-_t and Cl^- of uncontaminated soil sample,
The degree of confidence of the model obtained was 99.7% ($R^2 = 0.997$).

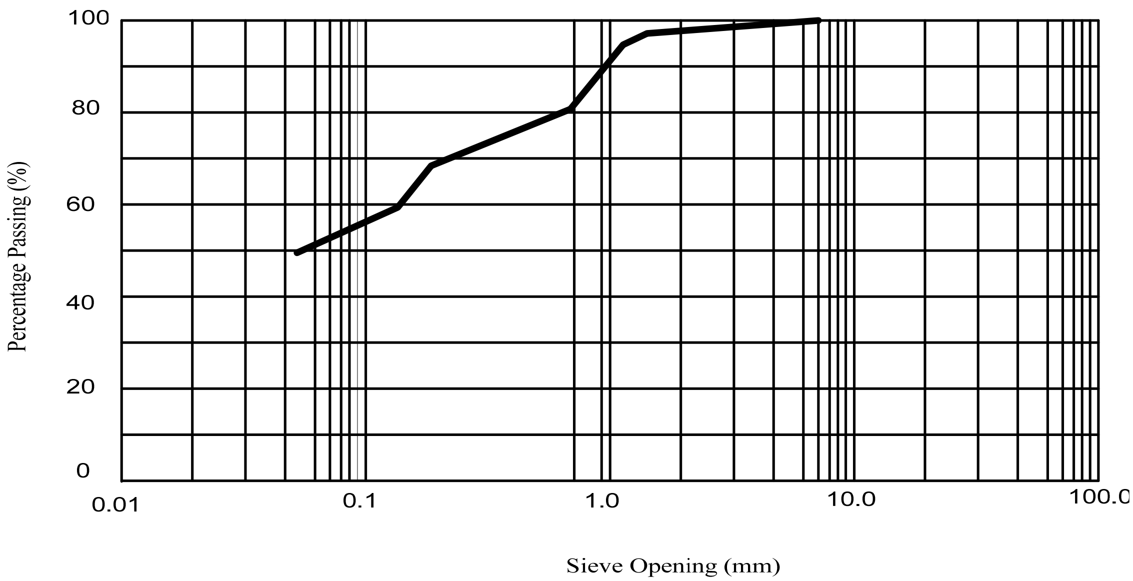


Figure 2: Grading Curve of Subgrade Soil Sample.

Table 1: Average Chemical Properties of Subgrade Soil Samples Contaminated with NaCl Solution.

Day of soil testing	Soil Sample Group											
	A1			A2			A3			A4		
	Na	CEC	Cl	Na	CEC	Cl	Na	CEC	Cl	Na	CEC	Cl
0	0.09	1.615	19.87	0.09	1.615	19.87	0.09	1.615	19.87	0.09	1.615	19.87
7	0.11	2.101	34.06	0.12	2.135	68.34	0.13	2.162	79.02	0.14	2.184	103.96
14	0.14	2.206	103.00	0.17	2.290	116.41	0.19	2.456	117.83	0.23	2.565	119.91
28	0.30	2.653	119.89	0.32	2.792	126.14	0.36	2.856	128.06	0.43	3.023	146.12
56	0.52	3.166	182.34	0.58	3.488	204.54	0.68	3.974	242.11	0.72	4.157	386.35
112	0.78	4.435	395.20	0.80	4.641	403.60	0.86	4.796	423.75	0.91	5.023	472.50
196	1.22	5.465	470.98	1.37	5.696	481.30	1.53	6.027	487.85	1.60	6.273	492.15
280	1.42	5.672	489.50	1.56	5.872	493.70	1.64	6.786	499.05	1.95	6.874	513.50
364	1.50	5.734	499.80	1.64	5.900	501.00	1.69	6.930	508.30	2.03	6.986	520.00

Day 0 values are for the control sample, measurement unit is cmol/kg

RESULTS AND DISCUSION

The particle size analysis of the subgrade soil sample was displayed Figure 2. The result showed that the soil was well-graded and has particles lesser than 0.045mm (i.e. 29.17%). The chemical test result showed that the values of Na^+, Cl^- and CEC increased from top to the bottom of the containers (Table 1).

There was significance gaining in the exchangeable ions as the salt solution travelled from the top to bottom of containers. The values of CBR for soil samples in group A1 decreased with days of soil interaction as shown in Table 2. The control soil sample

CBR value was 10.7% and at the end of 364 day this value has reduced to 8.9% for soil samples in group A1, 8.7% for A2 group, 8.4% for group A3 and 8.3% for those in group A4. During the determination of CBR values, the samples for the test were taken on the specified days at different levels in the containers. The chemical properties of the samples taken were not uniform (Table 1). This implies that the CBR values obtained at different days were independent and should be analyzed separately.

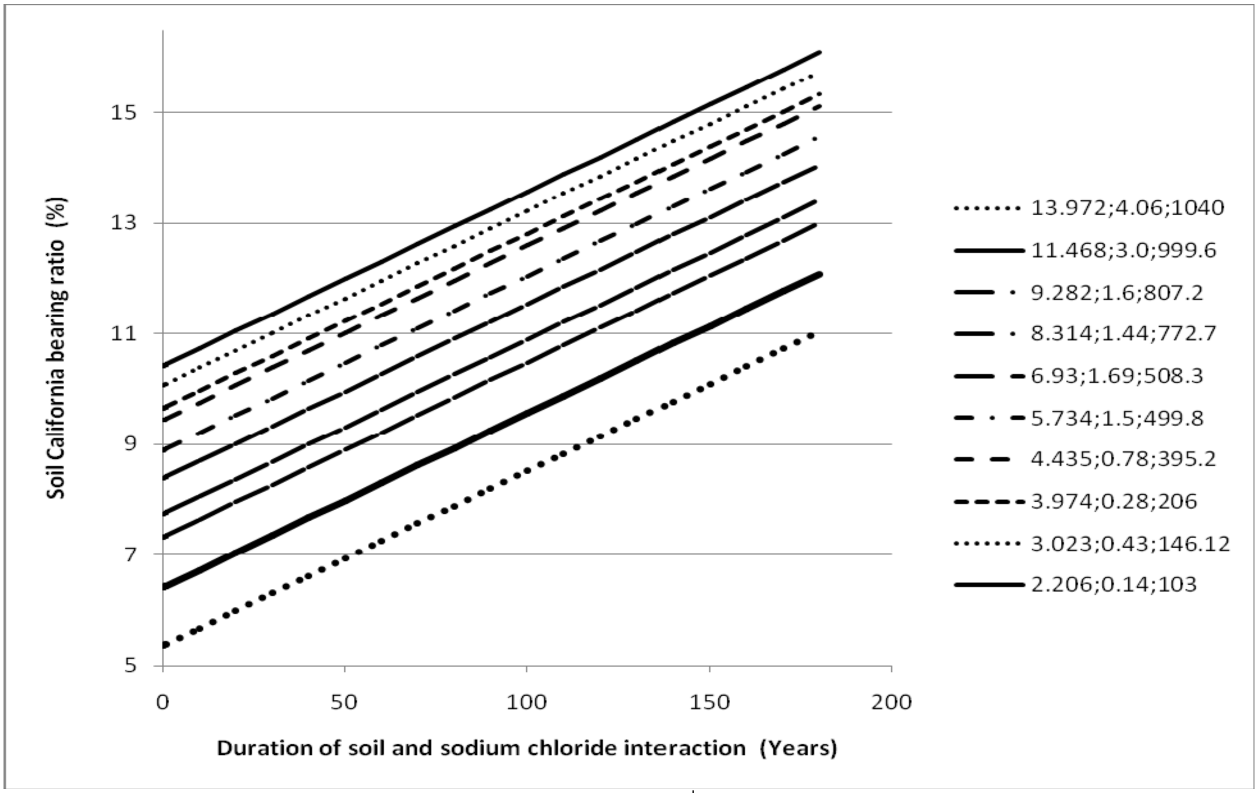
Table 2: Comparison between Model Results and Measured Results for Subgrade Soil under the influence of NaCl.

Time (Day)	Soil chemical properties in cmol/kg			Measured CBR (%)	Model CBR (%)	ΔCBR (%)
	CEC	Na^+	Cl^-			
control	1.62	0.09	19.9	10.7	10.7	0.00
7	2.10	0.11	34.1	10.4	10.5	-0.48
14	2.21	0.14	103.0	10.3	10.4	-1.04
28	2.65	0.30	119.9	10.1	10.2	-1.28
56	3.17	0.52	182.3	9.9	10.0	-0.81
112	4.44	0.78	395.2	9.4	9.4	-0.31
196	5.46	1.22	471.0	9.0	9.0	-0.3
280	5.67	1.42	489.5	8.9	8.9	-0.02
364	5.73	1.50	499.8	8.9	8.9	-0.61
7	2.14	0.12	68.3	10.4	10.5	-0.49
14	2.29	0.17	116.4	10.3	10.4	-0.39
28	2.79	0.32	126.1	10.1	10.2	-0.39
56	3.49	0.58	204.5	9.8	9.9	-0.62
112	4.64	0.80	403.6	9.3	9.4	-0.65
196	5.70	1.37	481.3	8.9	8.9	-0.04
280	5.87	1.56	493.7	8.8	8.9	-0.57
364	5.90	1.64	501.0	8.7	8.9	-1.58
7	2.16	0.13	79.0	10.4	10.4	-0.56
14	2.46	0.19	117.8	10.2	10.3	-0.67
28	2.86	0.36	128.1	10.1	10.1	-0.82
56	3.97	0.68	242.1	9.5	9.7	-1.25
112	4.80	0.86	423.8	9.2	9.3	-0.68
196	6.03	1.53	487.9	8.7	8.8	-0.75
280	6.79	1.64	499.1	8.6	8.5	0.96
364	6.93	1.69	508.3	8.4	8.4	-0.76
7	2.18	0.14	104.0	10.4	10.4	-0.25
14	2.57	0.23	119.9	10.2	10.3	-0.62
28	3.02	0.43	146.1	10.0	10.1	-0.71
56	4.16	0.72	386.4	9.5	9.6	-0.67
112	5.02	0.91	472.5	9.1	9.2	-0.55
196	6.27	1.60	492.2	8.6	8.7	-0.95
280	6.87	1.95	513.5	8.4	8.4	-0.36
364	6.99	2.03	520.0	8.3	8.4	-1.22

Day 0 is the control CBR value which is uniform for all samples

The model developed was used to determine the CBR values of the soil samples and these valves were compared with the measured values. The percentage differences were in the range of +0.96 and -1.28% as shown in Table 2. Based on the very low percentage difference obtained, the model was used to investigate the effect of maintaining given values of exchangeable Na^+, Cl^- and CEC in the soil sample for a long period of time its CBR. The results obtained for different values of Na^+, Cl^- and CEC were in Figure 3.

At low values of Na^+, Cl^- and CEC, the time for the soil to regain its initial control CBR value was very short while for higher magnitudes of Na^+, Cl^- and CEC, the recovery years were very high. Consequently, the recovery time for the sodium chloride contaminated soil was found to be function of soil exchangeable Na^+, Cl^- and CEC magnitudes. Figure 3 also revealed that contaminated subgrade soil experienced increase in CBR value after its recovery period has been exceeded. This aspect of the model needs further verification but could be disregarded in design of road which would result to conservative design.



Legend CEC =; Na^+ =; Cl^- =

Figure 3: Long-Term Effect of NaCl on Subgrade Soil CBR.

The concept of ion exchange can be utilized to explain the reason for the dropped in soil CBR values measured for the contaminated soil samples. In the salt solution were two ions namely exchangeable cation Na^+ and anion Cl^-. The Na^+ was attracted to the clay minerals and during the ion exchange, replacement of existing cation in clay element adsorbed layer with monovalent ion Na^+ would result to production of weak bond. The weak bond would offer least resistance to plunger penetration. The development would bring about reduction in soil CBR value. The model result revealed that the weak bond set up due to attraction of Na^+ to the adsorbed layer was not permanent. The initial soil CBR properties would improve with time depending on the soil Na^+, Cl^- and CEC levels.

CONCLUSIONS

The study revealed that the tested subgrade soil CBR was greatly affected by the presence of sodium chloride. The CBR value reduced with increase in the soil exchangeable ions Na^+, Cl^- and CEC values due to formation of weak bond as a result of attraction of exchangeable cation Na^+ in the adsorbed layer of clay elements. On the other hand, the model revealed that the tested subgrade soil has tendency to regain its original uncontaminated CBR value with time. The time was found to be a function of the soil exchangeable Na^+, Cl^- and CEC values.

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SUGGESTED CITATION

Ayininuola, G.M. and O.A. Agbede. 2009. "Influence of Sodium Chloride on Subgrade Soil California Bearing Ratio". *Pacific Journal of Science and Technology.* 10(1):573-580.

Pacific Journal of Science and Technology