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Utilization of Saline Water on the Mechanical Properties for Unbounded Granular Materials

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Abstract

It is well-known that three quarters of the world contain saline water. The saline water contains amounts of salt dissolved in water to a concentration of parts in per millions (ppm) includes sodium chloride, Sodium sulfate and magnesium sulfate. Compaction of Base coarse layer is usually done by water which is considered tap water. Cites near shores often need coastal roads to act as service roads parallel to shore lines. For this matter, the use of saline water in compaction is considered a main objective in this situation due to the decrease in transportation cost of Tap water used in hauling and compaction of base coarse layer. This research studies the effect of saline water on the mechanical properties of the unbounded granular material used in base coarse layer. The study compares the results between the use of saline water and standard tap water by subjecting both samples to different lab tests such as California baring ratio (CBR) and modified proctor. The results showed that saline water could be used successfully in the operation of constructing base coarse layer with good results concerning the amount of absorbed water content and maximum dry density of the base coarse layer which will result in good compaction. In addition, the CBR test results showed high evaluation of strength for samples contained saline water. The study used Dolomite material for base coarse layer from Jabal Ataqa as one of the most used aggregate types in EGYPT through construction.

Keywords

Saline water; CBR test; modified proctor test; base coarse layer; water content; maximum dry density.

1. Introduction

The main function of a base coarse layer in a flexible pavement is to provide sufficient cover over the subgrade, to decrease the stresses and strains induced by traffic loading so that subgrade shear failure does not occur and does not densify significantly, In addition, to a loss of shape for the pavement surface. To perform sufficiently, the base coarse must have a number of physical and mechanical properties such as Stability, durability, impermeability and workability to ensure adequate strength and stiffness under the applied traffic loads and the strength is maintained during its designed service life. To be suitable for use as base coarse material, gravel must be capable of developing an adequate bond between the bituminous surfacing and the base course, which is enhanced by a degree of penetration of the first bituminous application into the base course surface.

On the other hand, it is well known that saline water affect the road infra-structure negatively. The addition of salt in water with high levels of moisture is considered one of the main causes of pavement distress. Salt damage is mostly common in warm coastal regions. The damage caused to pavements by saline water had been the subject of a number of studies. This negative affect from saline water was due to the powdering phenomenon to base course. It is considered a common form of distress. It is revealed as loss of all cohesion beneath the surfacing. The result is a lack of bond between the surface treated and the base. This could easily result in failure under traffic *(Pirlea and Burlacu, 2008)*

2. Background

A number of laboratory tests were conducted with mixtures of different soils containing gravel with clay adding rock salt. The lab tests done were compaction, Atterberg limits, CBR, unconfined compression strength, and indirect tensile strength. Salt content was differentiated from 0.5 to 2.5% by dry weight. The 0.5% salt content was found to have no influence on the liquid or plastic limit. In addition, slight decrease in the liquid limit and a slight increase in the plastic limit were observed with increasing salt content. Through using the modified compaction test the dry unit weight was found to increase with salt content and the optimum water content was reduced by salt treatment. The CBR test showed significant greater CBR values for salt treated samples *(Singh and Das,1999).*

In another study, high saline water utilization was discussed through a number of lab tests, it was found that the presence of natural salts was found to have a positive effect on granular pavements but a negative impact on bituminous mixtures. In some cases, salts were found to have a very small positive effect on the tensile strength of the pavement material, which was likely related to clay chemistry interactions. In other cases regarding crystallization, salt mixtures were observed to form bonds with the pavement material, which led to a significant increase in tensile strength and some increase in shear strength *(De Carteret et al., 2010) and (Liu et al., 2015).*

Further studies on the effect of water in embankment of pavement were conducted, the study illustrated that water had played a primary impact role on embankment of pavement. It showed that water or moisture was one of the most important and partly unsolved parameters related to the deterioration of roads. It had an influence on the modulus of pavement layers and on the resistance against permanent deformation. In addition, Knowledge of moisture conditions in unbound pavement layers and subgrade soils were essential to predict the mechanical behavior of these materials in pavements, and to improve the design of pavements and their drainage systems.

The main objective of the research was is to increase the knowledge required for improving the highway performance and minimize the leaching of contaminants from roads and traffic. Finally, the research concluded that the improvement of pavement performance will lead to less road closures, better use of the road network, longer service life and more effective transportation of goods and people *(Boman and Gustafson, 2001).*

Another study, focused on sodium material presented in salt. It was for stabilization in clay soil, and desired compaction was obtained with less effort. It resulted in weak bond between soil particles. It was concluded that a increase in the strength and stability in the layer, It was shown that Salt had considerable use in stabilizing the surface of dirt roads with low traffic volume. When the mixture of salt, soil, and water are compacted, the mixture dries as a result of recrystallized salt that makes the resulting surface dense and hard. The salt strengthens the smaller soil particles together with the large particles.

In addition, when adding salt to the mixture, water should be added to obtain a moisture content within one to two percent of optimum. The salt crystals should be completely dissolved and the mixture should barely stick to equipment tires. In field, the mixture should be well graded and rolled with a pneumatic-tired roller. The road surface should have a glazed appearance and no moisture should arise on the surface. It was concluded that the effect of water type on compaction properties of soil is relatively small. Optimum moisture content and maximum dry density increases respectively with increase in salinity of water. The reasons suggested were that soil is not saturated and particles weren't soaked in water. In this condition the soil particles cannot interact freely with salts in water *(Alamdar, 1999).*

Further studies of effects for high salinity water on soil compaction had been done by applying tests on both natural soils and soils manufactured in the lab by combining a natural clayey soil with coarse grained sand. The study applied modified Proctor on selected samples. It was concluded that the use of high salinity water generally increased the maximum unit weight and decreased the optimum water content. The study performed California Bearing Ratio (CBR) tests on manufactured sand-clay mixtures used in compaction testing. The CBR test results showed a significant increase in CBR values for samples compacted with highly saline water *(Azadi et al., 2008).*

In addition, a research studied the use of saline water versus fresh water. The use of salt water resulted in increasing the maximum dry unit weight and decreased the optimum water content. The study also drew the attention there could be a major drawback from using high salinity water in compaction of soils. The reason was the increased corrosiveness of soil due to the ions present in the water. It was concluded that the use of saline water during compaction had a significant effect on several soil characteristics *(Waller and Kitch, 2014).*

Finally, from all studies mentioned above, using saline water should be considered a matter of study and should be put under several lab tests especially when source of Tap water tanks isn't available or far away from site. This study puts the light on this area of research through a number of tests to be able to understand its effect on granular unbounded materials used in base coarse layer.

3. Problem statement

The use of saline water has been a main concern to all countries that are located beside seas and oceans especially for road works. One of the main boundaries from using it, is the high concentration of salt dissolved in the water that could affect the workability and properties of materials due to the powdering of salt on the base coarse layer. The salt weakens the bond between aggregates which lead to failure due to load repetition under high traffic.

4. Research Methodology and objective

4.1. Material sampling and testing

In this research, the materials were sampled from actual aggregates collected from actual base coarse layer contains Aggragates type Dolomite gained from Jabal Ataqa. This kind of Dolomite is considered one of the most used aggregate types in Egypt through construction.

Preparation of samples followed closely CBR testing and modified proctor testing procedure in accordance with Egyptian specifications which is followed American Society for Testing and Materials (ASTM) D1883 and ASTM D1557. The study aims at utilizing saline water gathered from the Mediterranean Sea in Alexandria to be used for compaction regarding unbounded materials used for construction in base coarse layer. The study focuses on making a comparison between using Tap water and Saline water on unbounded materials used in base coarse layer. The comparison was made using a number of lab tests such as CBR and modified Proctor testing.

To achieve this aim an experimental program using a sample from a stock pile in field contained crushed dolomite type 6 resulted from crushers. The source of materials were from Jabal Ataqa. The mixture contained a variety of materials such as coarse aggregates, Fine aggregates and crushed sand. The mixture was subjected to a number of Lab tests such as Eligibility tests for materials, CBR and modified proctor test. Through these tests, saline water was used to evaluate the effect of salinity on the mixture of base coarse layer and the results are compared with the results from using standard Tap water.

5. Experimental work

5.1. Eligibility Tests Applied on Materials

The tests done in order to were sieve analysis, Resistance to abrasion of small size coarse aggregate by use of Los Angles Machine, Aggregate Specific Gravity & Absorption and elastic and plastic plasticity test.

5.1.1. Sieve Analysis Test

Sieve analysis test was performed on aggregate components to satisfy specifications according to Egyptian specifications and ASTM. The samples were taken from a stock pile in field contained crushed dolomite Type 6 resulted from crushers taken from Jabal Ataqa. The results are summarized in Table (1).

Table 1. Accepted percentage of passing forstandard mix due to Sieve analysis for aggregates used in base course mixture

Sieve number	Weight Retained (gm)	Cumulative weight (gm)	Ratio of Retained (%)	Ratio of Passing (Design Curve) (%)	Specifications for base coarse layer according to Egyptian code	
% passing sieve 2”	———	———	———	100	100	
% passing sieve 1.5”	7300	7300	11.6	88.4	70	100
% passing sieve 1”	5900	13200	21	79	55	85
% passing sieve 3/4”	8800	22000	34.9	65.1	50	80
% passing sieve 1/2”	6950	28950	46	54	———	
% passing sieve no. 3/8”	5100	34050	54	46	40	70
% passing sieve no. 4	8150	42200	67	33	30	60
% passing sieve no. 10	4800	47000	74.6	25.4	20	50
% passing sieve no. 40	6000	53000	84.1	15.9	10	30
% passing sieve no. 200	4450	57450	91.2	8.8	5	15

The other tests done for Eligibility testing were resistance to abrasion (Los Angles Test), Aggregate specific gravity, absorption, liquid limit and plastic limit. Total weight of specimen used was 63000 gm. The results are summarized in Table (2).

Table 2. Eligibility testing results for aggregate materials regarding base coarse mixture

Crushing test			
Water Type	**Tap water**	**Saline water**	**Egyptian specifications**
Specimens	Dolomitic Aggregates	Dolomitic Aggregates	
Crushing Ratio (%)	0.7	0.7	Not more than 5 %
Absorption and Specific gravity for Dolomitic aggregates material			

Continued on next page

Table 2 continued

Specimens	Tap water	Saline water	Egyptian specifications
% absorption	2.30	2.46	Not more than 10 %
Total unit weight	2.503	2.496	———
Dry unit weight	2.561	2.558	———
Apparent unit weight	2.656	2.659	———
Los Angeles (L.A.) abrasion loss test			
Specimens	Dolomitic Aggregates	Egyptian specifications	Egyptian specifications
Abrasion ratio after 500 rounds	28.5	Not more than 50 %	Not more than 50 %
Liquid limit and plastic limit (Atterberg limit test) (passing from sieve 40)			
Test type	Result of test (eye inspection)		Egyptian specifications
Liquid limit	None plastic		Not more than 30 %
Plastic limit			Not more than 6 %

The results for eligibility testing indicated that the materials used in the research were in permissible ranges according to Egyptian specifications. After testing the physical properties of the materials, the following step is to test the materials mechanical properties through modified proctor test and CBR test.

5.2. Modified proctor test

Laboratory compaction tests provide the basis for determining the percent of compaction and water content needed to achieve the required maximum dry density need for sufficient engineering properties, and for controlling construction to assure that the required compaction and water contents are reached. In the Proctor test, the soil is first air dried and separated into 4 samples which are placed in 10.16 cm in diameter soil mold. The water content of each sample is adjusted by adding water from 2 to 10% to reach maximum dry density. The mixture is then placed and compacted in the Proctor compactor mold in three different layers where each layer receives 25 blows of the standard hammer. After compaction for each layer, the surface is scratched in order to ensure distribution uniformity for the compaction effects.

At the end of the test, after drying the sample, the dry density and the water content of the sample is determined. Based on the results, a relation is plotted for the dry unit weight and the water content. In this relation, the maximum dry density regarding the optimum water content can be obtained. The results for base coarse sample using saline water and Tap water are illustrated in Table (3) and plotted in Figure (1).

Table 3. Modified pro ctor test results for base mixture using saline water and tap water

	Tap water				Saline water			
Sample number	1	2	3	4	1	2	3	4
Weight of container+ wet sample(gm)	3848	3978	4084	4059	3846	3957	4082	4065
weight of container empty (gm)	1860				1860			

Weight of wet sample (gm)	1988		2118		2224		2199		1986		2097		2222		2205	
volume of mold (cm³)	950								950							
wet density (gm\ cm³)	2.093		2.23		2.341		2.315		2.091		2.207		2.339		2.321	
Number of mold	12	14	18	23	27	21	15	6	4	7	11	16	25	29	32	2
Weight of Pan empty(gm)	21	21.7	21.2	22	22.6	20.4	21.5	22.3	21.6	20.8	23.3	22.2	21.5	20.4	21.9	21.1
Weight of mold + wet sample(gm)	145.4	148.5	144.8	152.3	158.1	150.6	163.3	157.5	148.9	145.9	154.4	158.8	157.2	163.2	161.6	168.6
Weight of mold + Dry sample (gm)	143	145.8	139.7	147.2	149.8	142.9	151.6	145.9	146	142.6	148.2	153.3	147.7	153.7	149.1	156.2
Weight of water(gm)	2.4	2.7	5.1	5.1	8.3	7.7	11.7	11.6	2.9	3.3	6.2	5.5	9.5	9.5	12.5	12.4
Weight of Dry sample (gm)	122	124.1	118.5	125.2	127.2	122.5	130.1	123.6	124.4	121.8	124.9	131.1	126.2	133.3	127.2	135.1
Ratio of water content (%)	2	2.2	4.3	4.1	6.5	6.3	9	9.4	2.3	2.7	5	4.2	7.5	7.1	9.8	9.2
Average ratio of water content (%)	2.1		4.2		6.4		9.2		2.5		4.6		7.3		9.5	
Dry density	2.05		2.14		2.2		2.12		2.04		2.11		2.18		2.12	

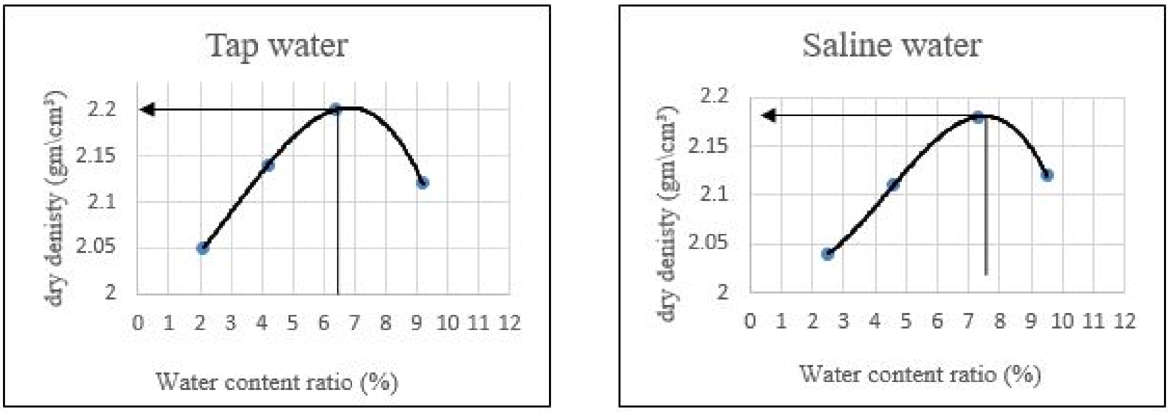

Figure 1. Relation between dry density and water content (modified proctor test)

5.3. CBR testing

The CBR test was developed as a method of evaluating the strength of the base course layer. It is a measurement of resistance to penetration for a standard plunger under specific density and moisture conditions. CBR test had been used to determine the material properties for pavement design and to evaluate the soil strength. The test used a standard piston with a diameter of 50 mm for penetration of the soil at a rate of 1.25 mm/minute. CBR value is calculated as a percentage of the actual load causing the penetrations of 2.5 mm or 5.0 mm to standard loads which are 1370 kg and 2055 kg due to standard crushed stones at 2.5 mm and 5.0 mm penetrations respectively.

The samples are divided in two groups as similar to the proctor test. The apparatus consists of a mould 150 mm diameter with a base plate and a collar, loading frame and dial gauges for measuring the penetration values and the expansion when soaking as shown in figure (2).

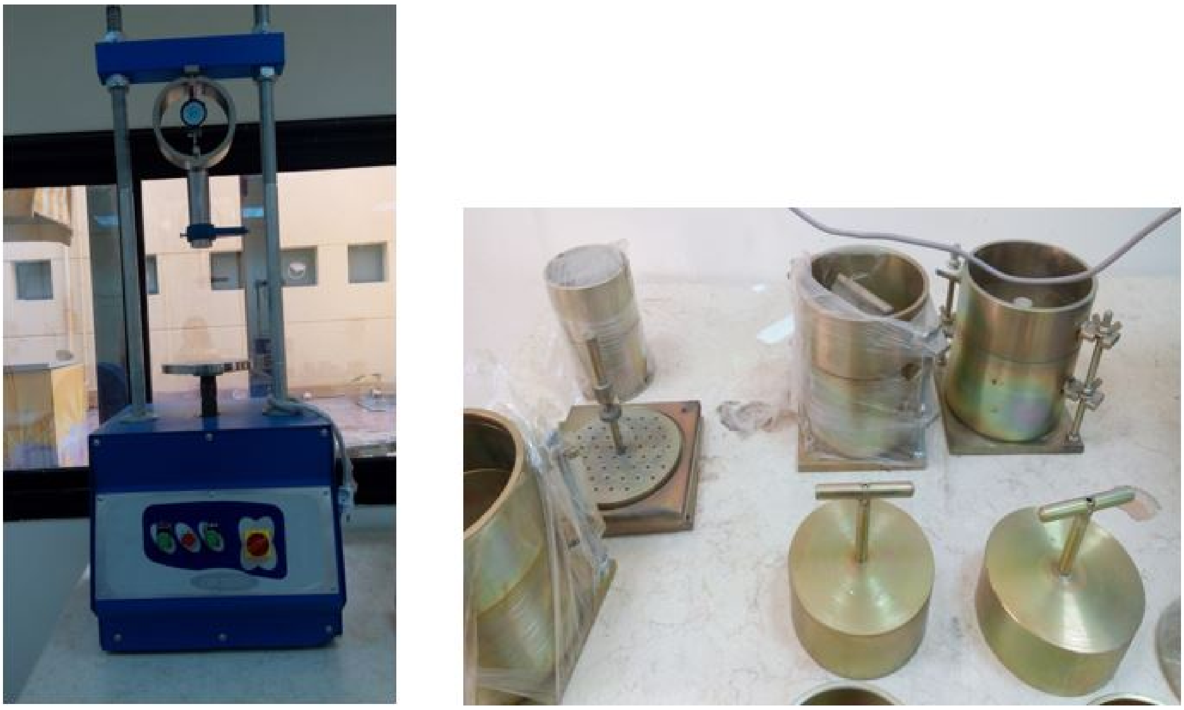

Figure 2. CBR test apparatus

The duration of soaking in water was for approximately four days and both the swelling and water absorption values were noted. The surcharge weight was placed on top of the specimen in the mould and the assembly was placed under the plunger of the loading frame. Finally, a relation between load and penetration was plotted and two value of CBR were obtained using equation (1).

$$CBR = \frac{Load\ due\ to\ penetration\ of\ sample}{Load\ due\ to\ standard\ specimen} \times 100 \tag{1}$$

The higher value between 2.5 mm and 5.0 mm penetration is selected. Both results from using saline water and Tap water are summarized in Table (4) and the relation between load and penetration is shown in Figure (3).

Table 4. CBR test results for samples containing saline water and tap water

swelling test			
Water type		Tap water	Saline water
A=Initial reading of micrometer		1	1
B=Final reading of micrometer		1	1
Swelling Ratio= (A-B/(container height))*100		0	0
Result		No swelling detected	
CBR Test			
Penetration in cm	0.0635	339.75	317.1

Continued on next page

Table 3 continued

	0.127	588.9	634.2
	0.1905	906	906
	0.254	1177.8	1132.5
	0.381	1449.6	1472.25
	0.508	1812	1766.7
Load at 2.5mm (kg)		1177.8	1133
CBR at 2.5 mm (%)		86.7	83.3
Load at 5 mm(kg)		1812	1767
CBR at 5 mm(%)		88.9	86.7

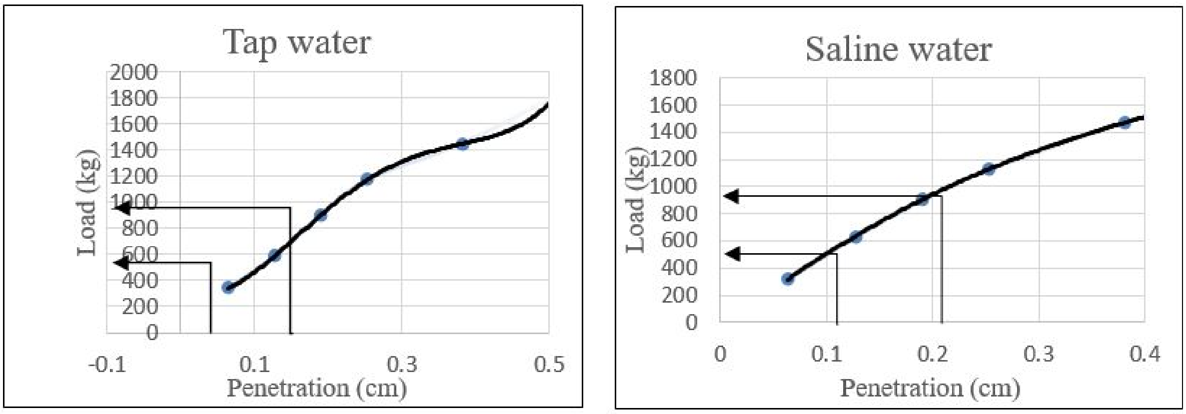

Figure 3. Obtained stress from relationbetween load and penetration

6. Analysis of results:

From results summarized in Table (3) and Figure (1), it is shown that maximum dry density from using saline water is slightly lower than of using Tap water. In addition, the water content in samples containing saline water is higher than the ones from Tap water. This is due to effect of saline water which increased the moisture ratio in the samples from 6.4% to 7.3%. This action decreased the maximum dry density from 2.2 to 2.18 gm/cm^3. In order to check these results, the ratio of saline in water content is quite variable from a sea to another but if the ratio of saline concentration in water was assumed to be 35% percent mostly, then this ratio can be calculated as in equation (2).

$$Ratio\ of\ moisture\ content\ in\ Saline\ water = (7.3 * (35\%) \setminus 100) = 0.025\% \tag{2}$$

The previous mentioned ratio is quite small and could be neglected. Besides, the results from samples containing saline water remained within permissible ranges regarding Egyptian specification. Other considerable aspect is the type of aggregates used in this study which is the Dolomitic aggregates. It is considered a dense graded aggregate material which contains minimum voids that increases the weight of sample in compaction process.

Furthermore, from results summarized in Table (4) and Figure (3), it showed that CBR values from samples added Saline water are also slightly lower from samples used Tap water but also still in permissible ranges. This is also due to the decreased maximum dry density which affected the stress to which the sample can endure during CBR testing.

7. Conclusions and recommendations

- In the process of road construction, the use of saline water is a major concern especially when Tap water isn't available or even far from site to decrease costs.
- Dolomitic aggregates were slightly affected by saline water due to the density of these aggregates which minimized voids between the aggregate particles which increased the weight of sample in compaction process.
- Maximum dry density in samples containing saline water was slightly deceased from samples using Tap water from 2.2 to 2.18 gm/cm^3.
- The water content in samples containing saline water increased from the ones containing Tap water from 6.4% to 7.3%.
- Results from the modified proctor test regarding saline water remained within the permissible ranges according to Egyptian specifications.
- Results from CBR testing regarding Saline water samples also remained within the permissible ranges according to Egyptian specifications.
- The concentration of saline in sea water is considered part per million and this doesn't affect the base mixture mechanical properties if used with dense graded unbounded materials due to minimum air voids.
- Saline water didn't affect the bond between the aggregates in the whole base mixture considering compaction.
- Further studies should be done on other types of Aggregates with saline water used in Egypt such as limestone.

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