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HYPER-SALINE SOLUTION OF QARUN LAKE (MAGNESIUM CHLORIDE) TO CONTROL DUST FROM UNPAVED ROADS AT FAYOUM, EGYPT

Abeer Hassan[1], Sameh Ahmed Galal[2] and Adel Abd Eltawab [3]

1 Graduate Student in Faculty of Engineering, Fayoum University

2 Highway Engineering, Faculty of Engineering, Fayoum University

3 General Manager in Egyptian Salts and Minerals Company

ABSTRACT

Magnesium chloride $MgCl_2$ is a naturally occurring material and is extracted from salt-water in Qarun lake at the Egyptian salts and minerals Co. in Fayoum, Egypt such as those found in seawater. Magnesium chloride can be adapted and designed to provide highest efficiency depending on prevailing dust conditions, anticipated traffic, and type of soil in Fayoum roads. Dilution can also be varied to obtain the greatest possible economy and minimize environmental impact. This soil may be best treated with a Magnesium chloride. The paper includes discussion on the extent of unpaved roads, the consequences of dust, categorization of road additives, and a way to dust control. The effect of $MgCl_2$ on the physical and mechanical properties of soils was evaluated in the laboratory. First, the physical and chemical properties of the soil sample were determined. Next, the swell percentage, California bearing ratio and indirect tensile strength tests were performed at different curing times on samples with and without the additive by compressing the sample to achieve particular compaction characteristics. The results show that dispersive and expansive clay soils can be effectively improved using an additive $MgCl_2$ solution.

KEY WORDS: Magnesium Chloride, Dust Treatment, Road Additives, Unpaved Roads, Road Stabilizers And Road Erosion.

INTRODUCTION

Unpaved roads are the principal component of the road network in most developing countries, and these roads are fundamental to economic and social development. These unpaved roads, and especially those surfaced with locally available or non-engineered materials, typically do not have the ideal range and distribution of particle sizes so it cause deteriorate quickly because of traffic and variable climatic conditions. This dust can penetrate the houses along unpaved roads causing nuisance, health problems because it can be a conveyor of diseases and air pollution. Also the cloud formed by fine suspended dust particles can impair the visibility and cause a hazard to drivers. Besides polluting the environment, the generation of dust means the loss of fines of road surface binders because it led to the thrown of coarse aggregates away from the road surface forming ruts, potholes and corrugations that require maintenance with a high cost and led to damages the road surface. A total of $2.3 billion worth of damage is caused annually by expansive soil problems in the United States alone **(Dhowian et al., 1988).** Because of high maintenance cost, dust control methods must be used such as reduction of vehicular speed and use of dust suppressing chemicals. Salts have been used for many years to control dust, and they have the side benefit of stabilizing the road surface resulting in reduced loss of gravel from the road surface and lower maintenance requirements. The two most common salts are calcium chloride and magnesium chloride. They are substances designed to bind to road dust and reduce the amount of dust that becomes airborne. Some studies show that magnesium chloride is more cost effective than calcium chloride. These suppressants would have to be applied anywhere from a couple times per year to once every 2-3 years to be effective **(United States Environmental Protection Agency Region 10)**. The current studies indicate that $MgCl_2$ is used on roads to control dust and humidity, to minimize coarse particle scattering **(Ketcham et al., 1996; Nixon and Williams, 2001; Transportation Research Board, 1991).** Magnesium chloride is very effective at reducing dust **(Evardsson, 2010; Sanders et al., 1994)** and make soil remains more hygroscopic at higher temperatures **(Piechota et al., 2004).** In studies by **Turkoz et al. (2014)**, the effects of a magnesium chloride ($MgCl_2$) solution on the swell potential, strength characteristics and dispersibility properties of clay soils were investigated and from the results, the ideal percentage of magnesium chloride solution to be added to the soil was 7%.

EXPERIMENTAL WORKS

1. Soil

The soil sample used in this study was obtained from the two selected roads in Fayoum. The depth of soil samples is about 50 to 80 cm below the ground surface. These experiments were made for natural soil and soil with various additive content according to American Society for Testing and Materials system (ASTM) during sampling and preparing of samples. Sieve analysis (AASHTO system), Consistency limits (ASTM D 4318-00), compaction (ASTM D 698-00), California bearing ratio (ASTM D1883-07) and indirect tensile strength tests were performed to characterize the soil sample and show how the additive effected on mechanical properties of the soil. The grain size distribution of the soil samples are presented in Figs. 1 and 2, respectively. The sample's index and chemical properties are summarized in Tables 1 and 2, respectively.

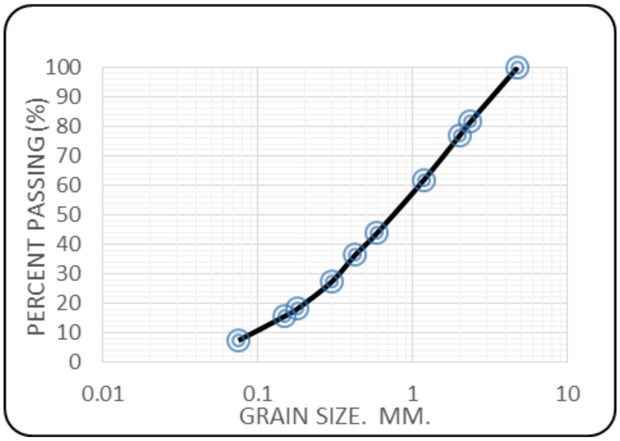
Table 1: Soil classification and Atterberg limits for natural soil

Sample	AASHTO system	USCS	L.L	P.L	P.I
Sample 1	A-1-B	SC	48.10 %	26.32 %	21.78 %
Sample 2	A-1-B	SC	49.18 %	25.67 %	23.51 %

Table 2: Some chemical characteristics of the considered soils

Soil	Conductivity (mmhos/cm)	TDS (mg/L)	Na(%)
Sample 1	2500	1350	65
Sample 2	2800	1450	70

TDS: Total dissolved salt.
Na: Sodium percentage.



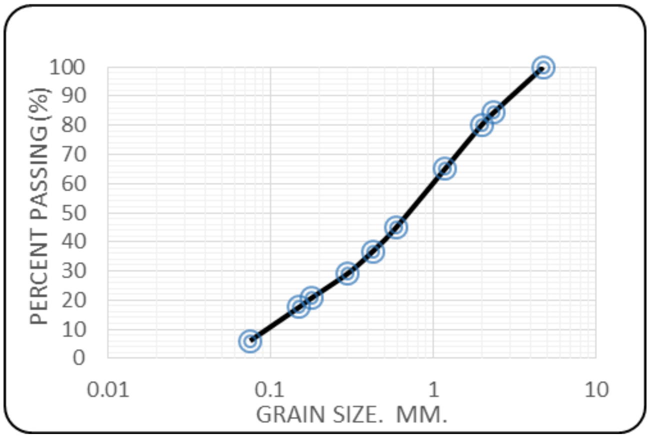


Fig. 1: Grain size distribution for natural soil of road 1

Fig. 2: Grain size distribution for natural soil of road 2

2. Magnesium chloride

The sample of $MgCl_2$ used in this study was obtained from the Egyptian Salts and Minerals Company in Fayoum. Although it can be used as a solid or in solution, the solution form is more common. It is very effective in reducing dust and it was chosen because of its attributes. The general properties of the ($MgCl_2$) solution used in this study are presented in Table 3.

Table 3: Properties of the $MgCl_2$ solution used in the study

Property	Quantity
Color/appearance	Slightly yellow
Baume degree	38
Density (g/cm3)	1.35
H2O (%)	61.8
Solid material (%)	38.2
MgCl2 in solid material (%)	73
PH (in 1% solution)	9.8

3. Sample preparation

Natural soil was dried at 120°C in a drying oven for 24 hours and then ground and passed through No. 4 sieve to obtain a uniform distribution. Then mixed with different amounts (2, and 4% by dry weight of the soil) of the magnesium chloride solution. All mixing was performed manually taking into account that the mixture must be homogeneous in each step. Mix properties used in preparing samples are presented in detail in table 4.

Table 4: Mix proportions used in preparing samples

Sample	Chloride Percent	MDD (gm/ m^3)	OWC (%)	Dry soil mass (g)	$MgCl_2$ solution (g)	Required water (g)	Added water (g)	Final mix proportion
Sample 1	2%	1.470	23.5	7500	150	1762.5	1612.5	7500 g + 150 g + 1612.5 g
	3%	1.692	12.5	7500	225	937.5	712.5	7500 g + 225 g + 937.5 g
	4%	1.498	20.0	7500	300	1500.0	1200.0	7500 g + 300 g + 1200.0 g
Sample 2	2%	1.540	23.0	7500	150	1725.0	1575.0	7500 g + 150 g + 1575.5 g
	3%	1.600	14.5	7500	225	1087.5	862.5	7500 g + 225 g + 862.5 g
	4%	1.518	24.0	7500	300	1800.0	1500.0	7500 g + 300 g + 1500.0 g

TEST RESULTS AND DISCUSSION

4. Atterberg Limits

Atterberg Limits tests were performed on each of the samples with different amounts (0, 2, 3 and 4%) of theMgCl2 additive. The liquid limits (LLs), plastic limits (PLs) and plasticity indices (PIs) are presented in Fig. 3 and Fig. 4 for road 1 and road 2 respectively. It is shown that the liquid limits of the samples decreased as the additive content increased. On the other hand, the plastic limit increased with the increase of additive content. Because the decrease in the liquid limit is larger than the increase in the plastic limit, the plasticity index decreased as the additive content increased. This can be explained by the reaction between magnesium ions and hydrogen, aluminum and silicon ions in clay to produce a gel cementitious agent which cement the soil particles. The silicate gel proceeds immediately to coat and bind clay lumps in the soil and to block off the soil pores. The reduction of the plasticity is mainly due to the rapid increase of plastic limit. The liquid and plastic limits generally stabilized at the 3% additive level.

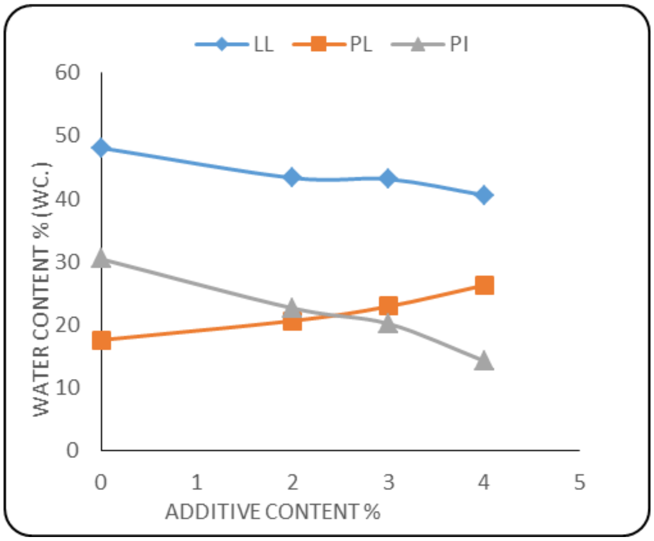


Fig. 3: Atterberg limits for sample of road 1

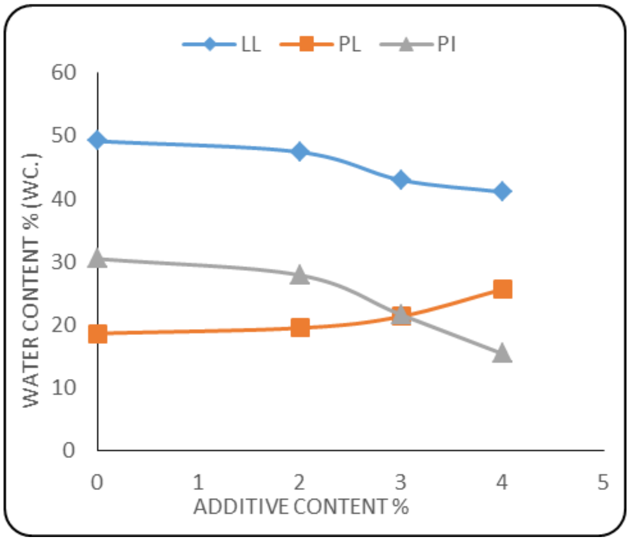


Fig. 4: Atterberg limits for sample of road 2

5. Compaction Test

Compaction tests were performed on magnesium chloride-soil mixtures in according with the standard mold of 4 in. It can be seen from the results, adding MgCl2 solution into the soil increased the dry density and reduced the optimum water content up to 3% MgCl2 for the same compactive effort. Figures 5 and 6 show the compaction curves for the MgCl2-soil mixtures for both roads. This increase in the dry density can be due to the particle flocculation and agglomeration caused by the rapid cation exchange in the soil–MgCl2 solution mixture as the soil particles tend to arrange in a flocculated structure and is dispersed when compacted. As the additive content was further increased up to 4%, the optimum water content (OWC) increased, and the maximum dry density (MDD) decreased slightly. The highest maximum dry density and lowest optimum water content were attained at an additive content of 3%.

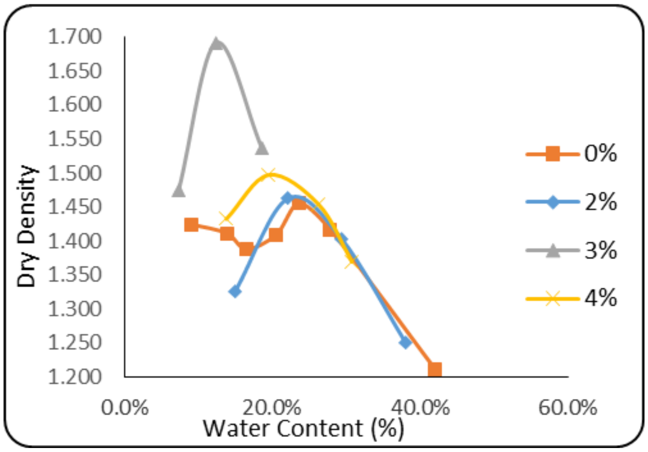


Fig. 5: Compaction curves of samples with different contents of $MgCl_2$ additive for road 1

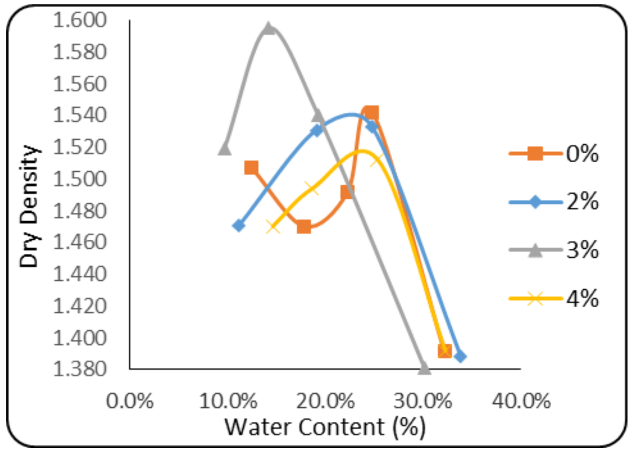


Fig. 6: Compaction curves of samples with different contents of $MgCl_2$ additive for road 2

6. Swell Tests

The swelling potential for the compacted samples for both roads were determined. The samples were compacted with a water content in the dry side of optimum so that 95% of the maximum dry density was obtained and submerged by water. There is no change in volume. Table 5 summarizes the results of swelling test (P_a) for the natural soil and mixed soil in two roads.

Table 5: The results of swelling test for samples

Sample	Road 1				Road 2			
	0	2%	3%	4%	0	2%	3%	4%
P_a	4.12%	3.68%	2.52%	1.40%	4.75%	3.47%	2.60%	1.90%

7. California Bearing Ratio Test (CBR)

The magnesium chloride-soil mixtures were cured for four days before tested. Table 6 summarizes the results of CBR tet for all additive contents. Figure 7 show the increase in the CBR values due to the addition of magnesium chloride for the two roads up to 3% and then decreased.

Table 6: Results of CBR values for soils with additive contents

Sample	Road 1				Road 2			
	0	2%	3%	4%	0	2%	3%	4%
CBR	2.50%	4.35%	5.30%	4.42%	1.80%	3.90%	4.00%	2.36%

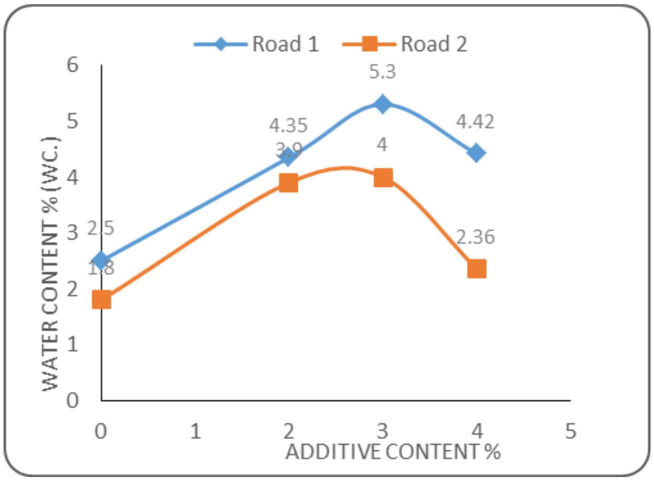


Fig. 7: Effect of $MgCl_2$ on CBR values for the two roads

8. INDIRECT TENSILE STRENGTH (IDT) TEST

The test is conducted by applying a compressive load to a cylindrical specimen. The test specimen is placed with its axis horizontal between the platens of the testing machine. The effects of the additive content and the curing time on strength of the sample are presented in Table 7. The strength is slightly increased between 7 days curing and 15 days curing. This study is stated that the effect of the duration of curing on strength values is more significant for clayey sand soils. Figure 8 show the sample tested for IDT test for the two roads.

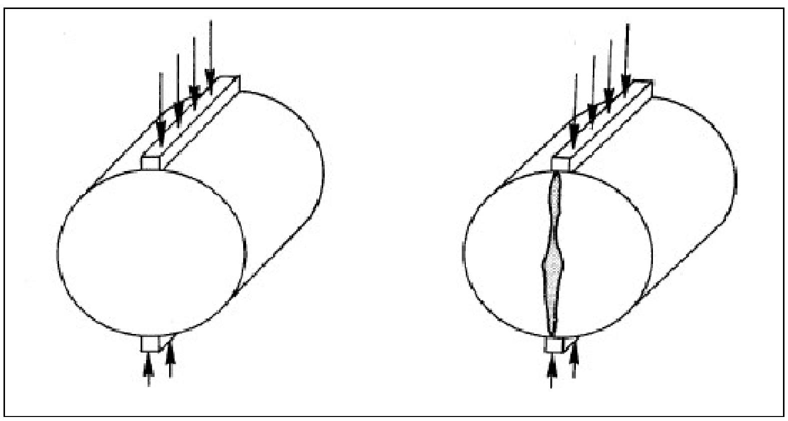


Fig. 8: Indirect Tensile Tests during Loading and at Failure

In clayey soils, the cohesion has a strong influence on the strength, and increasing cohesion is assumed to correspond to increasing strength. When the MgCl2 solution content was increased to 3%, the cohesion increased. It has been observed that at a 3% MgCl2 solution content, cohesion of the soil increases from 1.405 Kg/cm^2 to 1.505 Kg/cm^2 for road 1 and increase from 1.312 Kg/cm^2 to 1.441 Kg/cm^2 for road 2 at 7 and 15 days of curing periods respectively. Thus, Table 6 clearly shows the significant effect of curing on the strength behavior of soil–MgCl2 solution mixes. The opposite trend was observed when the additive content exceeded 3%. At contents of 4%, the cohesion decreased.

Table 7: Effects of additive content and curing time on strength

Samples	Additive percentage (%)	7 days curing (Kg/cm^2)	15 days curing (Kg/cm^2)
Road 1	0	0.827	0.849
	2	1.041	1.098
	3	1.405	1.505
	4	1.156	1.241
Road 2	0	0.849	0.877
	2	0.977	1.063
	3	1.312	1.441
	4	1.027	1.077

CONCLUSION AND RECOMMENDATIONS

CONCLUSION

1. The adding of magnesium chloride in different contents to the natural soil for the two selected roads increasing the plastic limit.
2. Adding magnesium chloride lead to reduction in plasticity index when adding as was highlighted by Murat Turkoz et al (2014).
3. It can be seen from the results, adding MgCl2 solution into the soil increased the dry density and reduced the optimum water content up to 3% MgCl2 for the same compactive effort.
4. Increase in the CBR values due to the addition of magnesium chloride for the two roads up to 3% and then decreased.
5. Magnesium chloride stabilization treatment at 3.0% pure chloride improves dense graded aggregate more than other additive contents that leads to decreases in dust and aggregate loss.

RECOMMENDATIONS

1. Field test study should be performed to the stabilized road to study and analyze the actual construction difficulties.
2. Develop special contract requirements to specify and allow the use of various dust and roadway stabilization products.
3. Economic analysis should be conducted. The durability service life and the cost of maintenance should be considered in a further study.

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