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EFFECT OF CHEMICAL ADDITIVES ON ENGINEERING PROPERTIES OF BASE AND SUB-BASE LAYERS

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ABSTRACT

The main objective of this work was to analyze the use of lime, bitumen and sodium chloride in base course material stabilization. Evaluation of strength properties of stabilized soil materials conducted by California Bearing Ratio (CBR) test. The material used in this research is crushed stone used as base and sub-base layers. The obtained results present that the lime has significant effect on strength improvement of stabilized layer. Also, 9% lime content is recommended to be the optimum to increase the bearing capacity as this content verifies standard specification of base layer which must be not less than 80% of CBR value. While emulsion bitumen and sodium chloride have positive effect on strength improvement, but not enough with respect to standard specification for stabilizing base course material. Consequently it should use another stabilizer with bitumen or sodium chloride to obtain required results for increasing strength of the stabilized layer.

KEYWORDS: Bitumen, CBR, Crushed Stone, Lime, Sodium Chloride, Stabilization, Strength Improvement

INTRODUCTION

Soil stabilization methods are required when a given site does not have suitable engineering properties to support structures, roads, and foundations. One possibility is to adapt the foundation to the geotechnical conditions at the site. Another possibility is to try to stabilize or improve the engineering properties of the soils at the site. Depending on the circumstances, this second approach may be the most economical solution to the problem. This second approach includes mechanical as well as chemical stabilization. Mechanical stabilization is produced by compaction. Chemical stabilization is achieved by mixing the soils with additives such as calcium chloride, Portland cement, lime, and fly ash,…etc.[1-3]

Soil stabilization is the alteration of the property of a locally available soil to improve its engineering performance, such as strength, stiffness, compressibility, permeability, workability, and sensitivity. Soils could be stabilized by mechanical, chemical, electrical, or thermal means. Chemical stabilization includes the addition of cement, lime, asphalt, chemical compounds, or a combination of those. The first controlled soil-cement construction was a road built in 1935 near Johnsonville, South Carolina, U.S.A. [4-6]. Since then soil-cement has been increasingly used as a satisfactory base, sub-base, and to improve the sub-grades for modern highway and airfield pavements. Lime as a soil stabilizer is among the oldest techniques for road construction, dating back to the Romans. Lime reduces the plasticity of highly plastic soils and hence makes them more workable. Lime is used as an additive to soil-cement to improve the cement reaction of some organic soils to facilitate pulverization and mixing and to improve the strength of plastic soils. [7-10].

As investigated by El-Hoseiny [11], lime and fly ash can be successfully used in expansive soil stabilization field by amount of 6% for lime and 15% for fly ash to increase strength and decrease percent swell. Second technique is concerning with stabilizing the soil by using layers of geosynthetic materials as geogrid layers, which give significant reduction in amount of swell and swelling pressure are measured with increasing number of geogrid layers. Also, Saad Aiban [12] study the performance of lime stabilized sabkha soil from Ras Al-Ghar, Saudi Arabia which has low density and strength in natural state, addition of lime improve the strength depending on molding moisture, curing regime, and presence of salt in sabkha soil. Maradi and Safapour [13] analyzed the use of combined cement and bitumen emulsion in base course stabilization on road projects in heart-Afghanistan, they confirms that the base stabilized using combined cement and bitumen emulsion increases the bearing capacity of the pavement effectively, this causes increase of allowable equivalent standard axle load and consequently, the life time of road will increase, in second variant total road layers decreased, which decrease the construction time period. Tamadher Abood [14] investigated the effect of adding different chloride compounds (Nacl, $Mgcl_{2,}$ $Cacl_2$) on the engineering properties of light brown salty clay soil from Iraq, and found the increase in salt contents leads to an increase in the unconfined compression strength. The addition of $Cacl_2$ to soil causes hardening and more strength as compared to the soil specimens containing other salts additives.

EXPERIMENTAL WORK

Used Materials

The base soil used in this research is crushed stone used as base and sub-base layer. This material was obtained from road construction in Qalubeya governorate. It was brought from Suize quarries in Suize region, Egypt. The used lime is one of the commercially hydrated lime {Ca $(OH)_2$} used in construction works. The hydrated lime is produced by Tura Company for cement. Analysis supplied by the manufacturer is indicated in Table 1. The used bitumen is of emulsion bitumen (anionic –ve) type with commercial name of (Ceroplast) produced by Chemicals of Modern Building Company (CMB). Analysis supplied by manufacturer is indicated in Table 2. On the other side, the physical properties of the used soil are shown in Table 3. Moreover, this soil contains different ranges of coarse size particles as shown in Table 4.

Table 1: Specification of the Used Hydrated Lime

Specification	Minimum Limit	Maximum Limit
Calcium hydroxide. $Ca(OH)_2$%	70%	85%
Silicon oxide. SiO_2%	------------	2%
Magnesium oxide. MgO%	------------	1%
Aluminum and iron oxide, $(Fe_2O_3+Al_2O_3)$%	------------	0.5%
Calcium carbonates, Ca CO_3%	------------	15%
Moisture,(H_2O)%	0.5	1.05%
Fineness: Sieve 0.211 mm (%) Sieve 0.90 mm (%)	------------ ------------	3% 6%

Table 2: Bitumen Specification for Producing Bitumen Emulsion at 25^{o}c

Penetration Index at Softening Point	Flash Point (^{O}c)	Softening Point (^{O}c)	Penetration At 25 ^{O}c	Unit Weight 25 ^{O}c	Ph
-0.27	320	52	60	1.012	9:11

Table 3: Basic Soil Properties

Soil Properties	Results	Specification Limits
Los Anglos abrasion percentage	43%	<= 50%
Percentage of water absorption	8.3%	<= 10%
Water content	1%	
Specific gravity (G_s)	2.60	
Liquid limit (LL)	—	<= 30%
Plasticity index (PI)	—	<= 8%
Passing no. 200 sieve	0	<=20%

Table 4: Sieve Analysis Results

Sieve Size (mm)	% Passing	Specification Limits
50	100	100
37.5	67.7	70 – 100
25	14.2	55 – 85
22.4	5.4	–
19	1.7	50 – 80
9.5	0	40 – 70
Pan	0	–

Three different types of stabilizers and different increased dosages level of each stabilizer were investigated. These types are: (a) Lime (with dosages of 3%, 4%, 5%, 7%, 9%, and 10%), (b) Bitumen (with dosages of 3%, 4%, and 5%), and (c) Sodium Chloride (with dosages of 3%, 4%, and 5%). Curing period of 7 days was adapted to investigate the effect of additives on the engineering properties of base materials.

Sample Preparation

The oven-dried samples were mixed with required chemical stabilizers at optimum moisture content and dry unit weight levels with 10% powder of limestone passing sieve No 200. Then, the soil mixtures were subjected to impact compaction in five layers to prepare compacted samples. After compaction, the soil samples were kept in humidity and temperature of the room for the required curing period.

The sample preparation of the soil-bitumen by cold mixing is applied by adding emulsion bitumen and mixing them effectively. The samples are formed without adding any water. Then, they subjected to impact compaction at layers and kept them for the required curing period at room temperature.

Compaction Results

Modified proctor tests were first conducted on control material to determine the optimum moistures content and maximum dry unit weight. Relationship between moisture content and dry unit weight of raw soil are shown in Figure 1.

From this figure it is evident that the optimum moisture content of natural material is at 6.7% which gives maximum dry density of 2.063 ton/m^3.

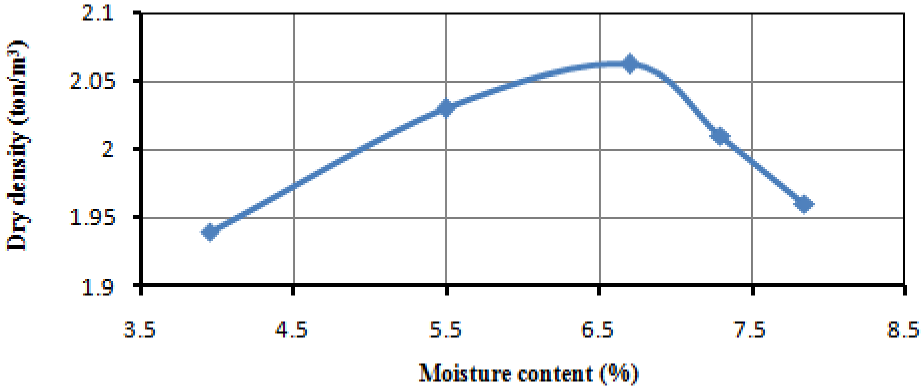

Figure 1: Modified Proctor Curve for Natural Material

California Bearing Ratio (CBR) Test

Figure 2 indicates that the value of CBR test for the natural soil material is 35% (at 0.2" penetration). This result confirms that, this material can be used as sub-base layer for urban roads only on condition that its CBR shouldn't be lower than 25%. But this material can't be used as a base layer since its CBR shouldn't be lower than 80% for rural roads or 60% for urban roads [15]. So, stabilization have been made to improve this material and try to make it suitable for use as base and study the effect of using different stabilizers on the strength of the tested material.

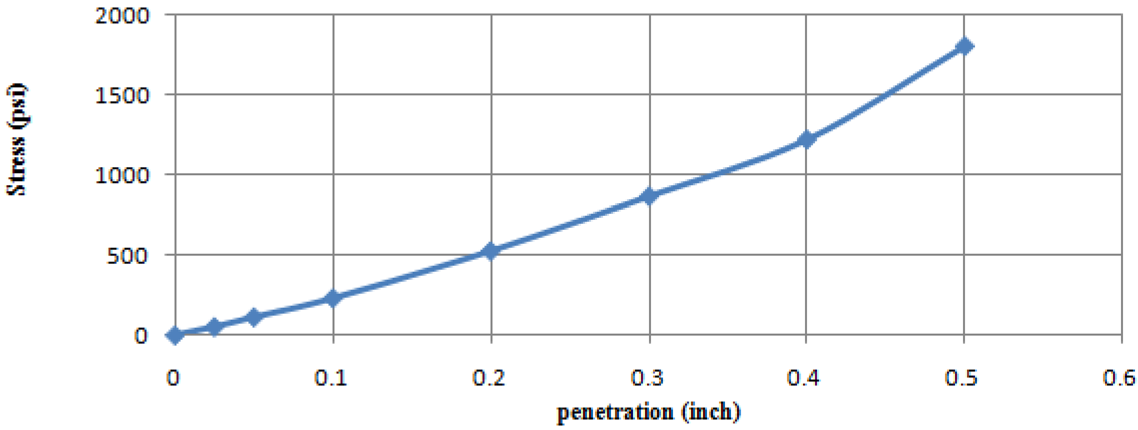

Figure 2: CBR Curve for Natural Material

RESULTS AND DISCUSSIONS

Effect of Lime Stabilization on Strength Properties of Tested Material

The CBR values for lime stabilized material from CBR test results are listed in Table 6. Also, Figures 3 and 4 illustrate the effect of lime on strength properties at contents 3%, 4%, 5%, 7%, 9%, and 10%. It is evident that, the CBR value increases with increase of lime content. For more indication, the lime contents of 3%, 4%, and 5% can't be used as stabilizer for base course because the CBR values are lower than 60% as Egyptian code [15]. But, they can be used as stabilizer for sub-base layer for urban and rural roads (CBR value more than 40%). Additionally, the lime content of 7%

can be used as stabilizer of base layer for urban roads where CBR value is more than 60%, but cannot be used for rural roads which need CBR value not less than 80%.

Moreover, lime contents of 9% and 10% provide a CBR value more than 80% which allow to use the stabilized material as a base layer for rural and urban roads. The increase of CBR value of the stabilized material with the increase of lime content is attributed to the cementation effect of lime where the reaction between material and lime forms various types of cementing agents. These cementing agents are generally regarded as the major source of the strength increases noted in lime-soil mixtures. The reaction results in the formation of various cementing agents that increase mixture strength and durability. Figure 3 indicated that the CBR value of the soil stabilized by lime increases to a certain value and after that the effect of lime isn't noticeable. The results indicated that the optimal lime content is 9% as it yielded the highest value of CBR (83.90%).

Table 5: CBR Value of Stabilized Material with Different Lime Content

Lime Content	3%	4%	5%	7%	9%	10%
CBR (%)	50.21	51.27	55.80	66.51	83.90	80.05

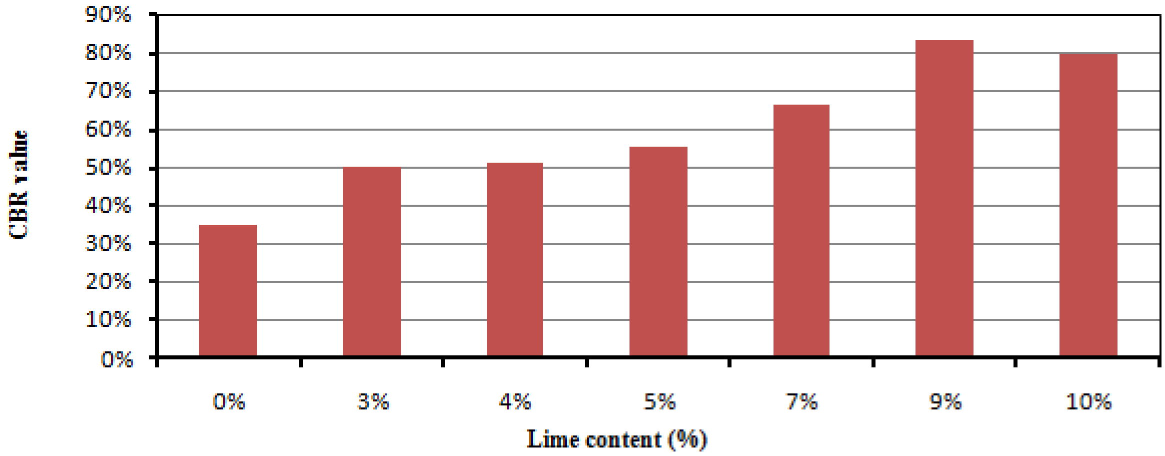

Figure 3: CBR Value of Stabilized Material by Lime at Different Contents

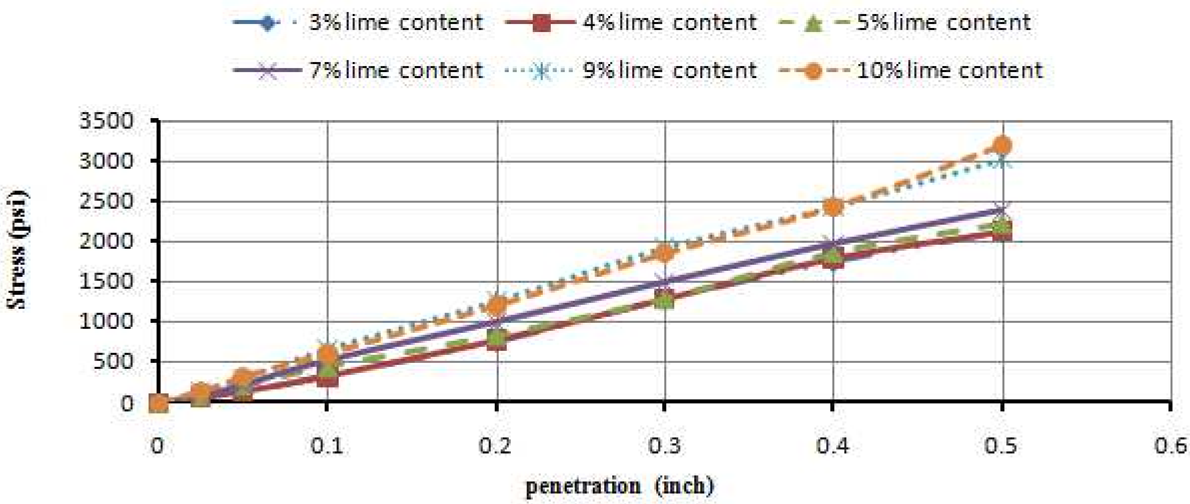

Figure 4: CBR Curve of Stabilized Material with Different Lime Contents

Figure 4 demonstrates the collecting curves for CBR tests for all contents of lime which present that for small contents 3%, 4%, and 5% the curves near to other then increase for 7% and reach largest difference at 9% and come to decrease after that at 10%, which mean 9% lime content is the optimum for increasing strength of tested material.

Effect of Bitumen Stabilization on Strength Properties of Tasted Material

The CBR values for Bitumen stabilized material are indicated in Table 6. The variations of CBR test results of the stabilized material with emulsion bitumen at contents of 3%, 4%, and 5% are shown in Figures 5 and 6. Where, the results need to correction due to inside curvature of first results. It is clear that the value of CBR for 3% emulsion bitumen content is more than 60% which allow stabilized base to use for urban roads only. But, for the content of 4% and 5%, CBR value is less than 60%. Therefore, for all contents the stabilized material can be used as sub-base layer for urban and rural roads (CBR value is more than 40%). Generally, the CBR value decreases with the increase of bitumen content between 3% and 5%. This may be attributed to viscous consistency of bitumen due to the partial softening that occurs especially with the increase of temperature. This viscous consistency facilitates sliding of the particles on each other; therefore the piston of the CBR test device easily penetrates inside the tested material.

Table 6: CBR Value of Stabilized Material with Different Emulsion Bitumen Content

Bitumen Content	3%	4%	5%
CBR (%)	60.95	57.14	53.33

It is noticed that stabilization of soils with bitumen differs greatly from cement stabilization. In non-cohesive materials, such as sand, gravel, and crushed stone, two basic mechanisms are active: waterproofing and adhesion. Soil particles are coated with bitumen that prevents or slows the penetration of water, the aggregate particles adhere to the bitumen and thus the bitumen acts as a binder or cement, acting to increase strength by increasing cohesion. In addition, bitumen stabilization can improve durability characteristics by making the soil resistant to the detrimental effects of water such as volume, thereby reduces the tendency of the material to lose strength in the presence of water.

It is concluded that it is better to use the bitumen as a waterproofing agent instead of using it as a stabilizer especially in high temperature climate countries. If it is required to obtain a desirable stabilization with high strength properties, bitumen can be mixed with another stabilizer as cement, lime, or fly ash. The role of combined cement and bitumen or lime and bitumen is to increase the stiffness and elasticity of the stabilized layer.

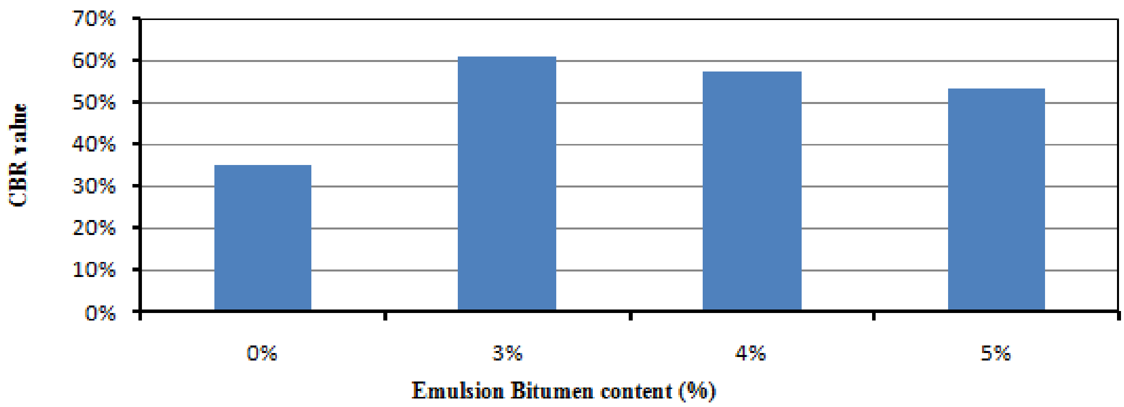

Figure 5: CBR Value of Stabilized Material by Emulsion Bitumen at Different Contents

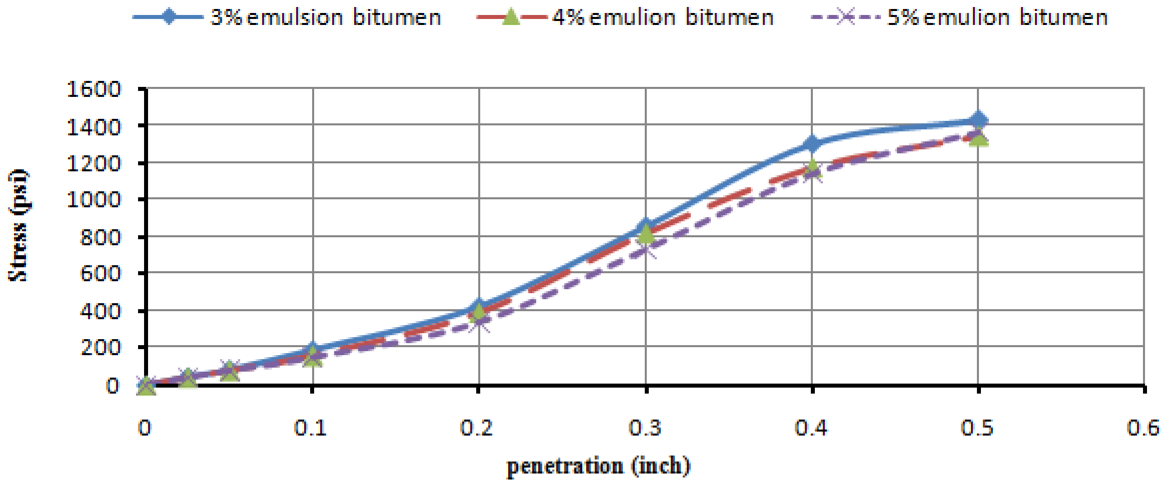

Figure 6: CBR Curve of Stabilized Material with Different Emulsion Bitumen Content

Effect of Sodium Chloride Stabilization on Strength Properties of Tested Material

The CBR values for Sodium Chloride stabilized material are listed in Table 7. Moreover, Figures 7 and 8 reveal the variation of CBR test results of the stabilized material with Sodium Chloride at contents of 3%, 4%, and 5%. It is evident that the CBR value increases for all contents above natural material with value more than 60%. Therefore, these contents allow stabilized base to use for urban roads and can be used as sub-base layer for urban and rural roads (CBR value more than 40%). But, it cannot be used as base layer for rural roads as CBR value less than 80%. The Sodium Chloride content of 4% gave the best increase of CBR value, as Sodium Chloride like any salt react with compound of tested material and bind particles and increase friction between particles which leads to increase strength [16]. The CBR value increases with the increase of Sodium Chloride content for 3% and 4% then decreases at 5% content. This may be attributed to sodium chloride absorb moisture from surrounding humidity. Therefore, the moisture increases in the tested soil. Consequently, this causes softening or lubrication of particles, this facilitates the penetration of piston inside the tested soil which in turn decreases the CBR value.

Moreover, Sodium Chloride can be used as a stabilizer for other purposes like maintaining the moisture in soil, absorb moisture from surrounding for using in hot climate to conserve the soil from volume changes. Figure 8 present the curves of stress and penetration for all contents of Sodium Chloride. It clears that 5% Sodium Chloride content is the highest curve, but that does not mean 5% content give the most increase of strength for sodium chloride stabilization because there is correction for result.

Table 7: CBR Value of Stabilized Material with Different Sodium Chloride Content

Sodium Chloride Content	3%	4%	5%
CBR (%)	62.86	64.76	60.95

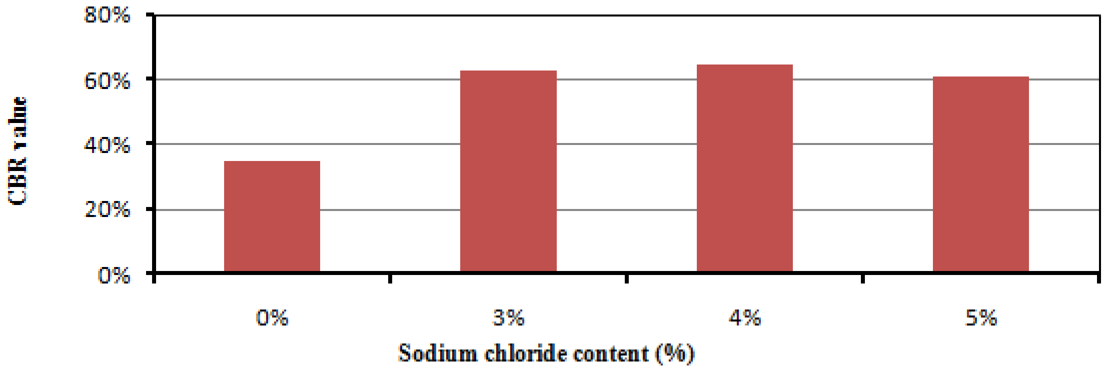

Figure 7: CBR Value of Stabilized Material by Sodium Chloride at Different Contents

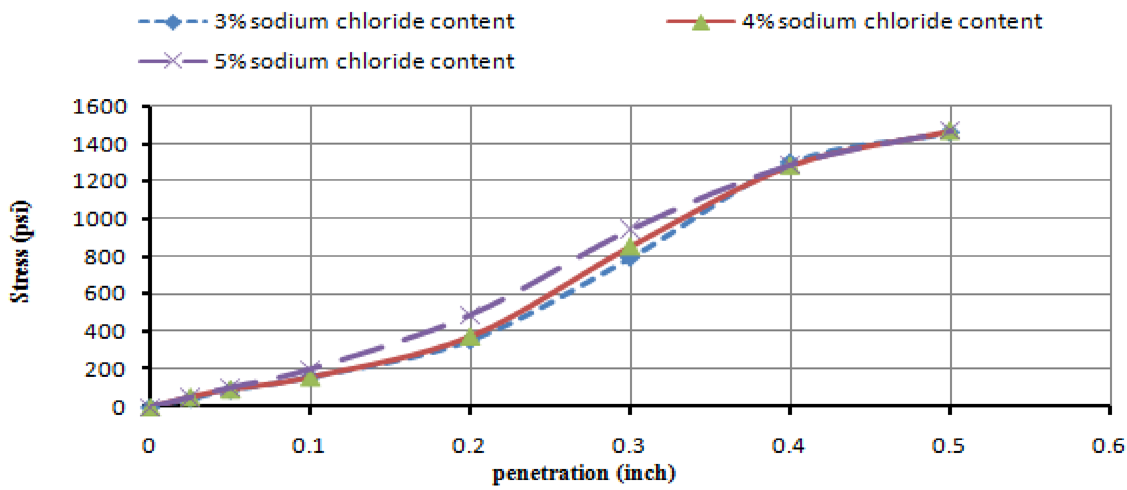

Figure 8: CBR Curve of Stabilized Material with Different Sodium Chloride Contents

Comparison between Types of Stabilizer

Figure 9 show the comparison of CBR value for different stabilizers (Lime, Emulsion Bitumen, and Sodium Chloride) for percentages of 3%, 4%, and 5%. This comparison illustrate that Sodium Chloride is the best type of stabilizers at these contents. The values of CBR for all types of stabilizers exceed the CBR value of natural material, and satisfy the specifications for urban roads (CBR has to be not less than 60%) for Sodium Chloride and emulsion bitumen. For lime it must be use content above 5% to satisfy the requirements to be used as a base layer for road construction, so for 7% lime content the CBR value reach to 66.51% for using as base layer for urban roads, while for 9% reach to 83.9% which allow stabilized material to use as base layer for rural roads, then the CBR value decrease at 10% lime content.

While bitumen present positive effect on CBR value, but the increase of emulsion bitumen content leads to decrease the CBR value of the tested material in climate conditions, so emulsion bitumen can be used as a stabilizer of tested material to be used as base layer for urban roads, but for rural roads bitumen can be used with another stabilizer such cement, lime, and fly ash to obtain good results for strength improvements.

The same with sodium chloride which has positive effect on CBR value in spite of the increase of sodium chloride content leads to increase the CBR value of the treated material, but still lower than the CBR value of base layer for rural roads. Consequently, it needs to use another stabilizer with sodium chloride for strength improvement of tested material for rural roads.

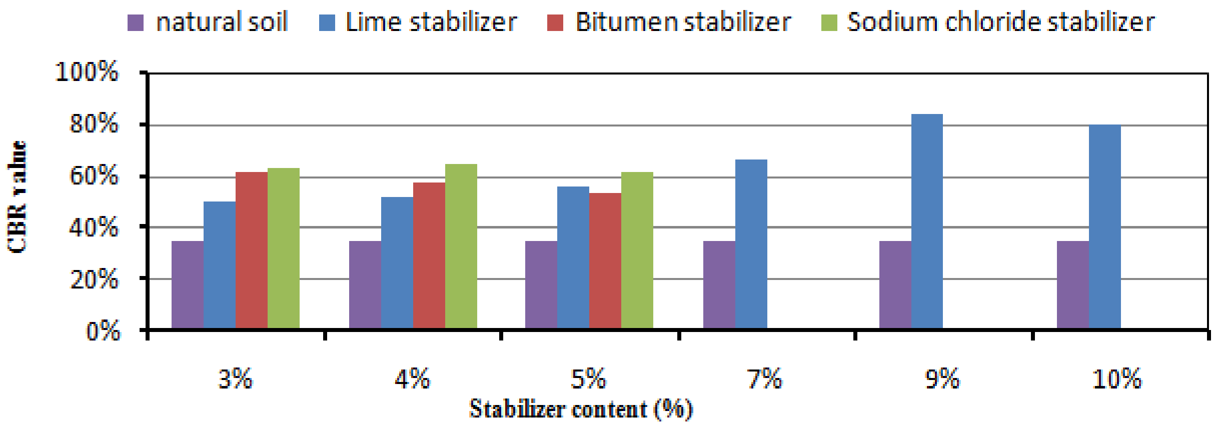

Figure 9: Comparison of CBR Value for Material Stabilizers

Rate of Increase of CBR Value for Stabilized Material

Figure 10 show percentage of increase of CBR value when using lime for stabilization. The increase percentage is small for low lime contents (3%, 4%, and 5%) and increase with large values at 7% lime content reaching the peak value of 139.7% at 9% lime content, beyond this value, the increase percentage come to decrease. The rate of increasing is small at small lime contents (3%, 4%, and 5%), then the rate increase between 5% and 7% after that the rate has the maximum value of increasing between 7% and 9%, which means that the optimum lime content is between 7% and 9% range of lime content. Consequently the best content of lime for stabilizing tested material is between 7% to 9% which needs economic evaluation to choose the optimum content.

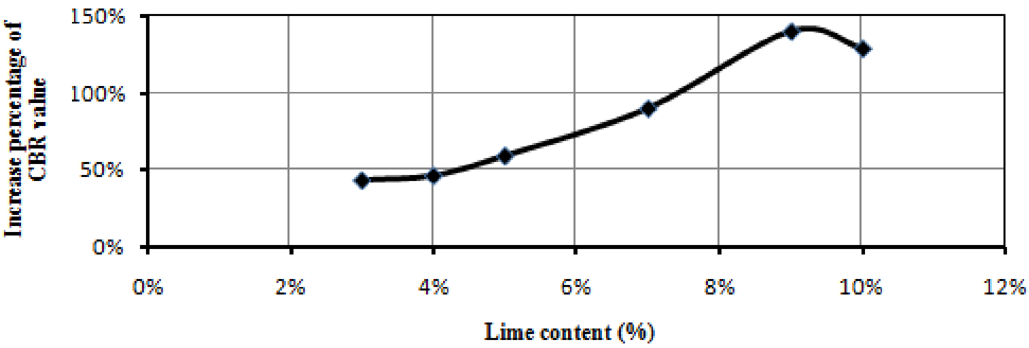

Figure 10: Increase Percentage of CBR Value for Lime Stabilizer Contents

Figure 11 show increase percentage of CBR value when using emulsion bitumen for stabilization. The rate of increase decreased between 3% to 5% emulsion bitumen content. The increase percentage decreases with increase of emulsion bitumen content; this means that 3% is the best content of emulsion bitumen for stabilization.

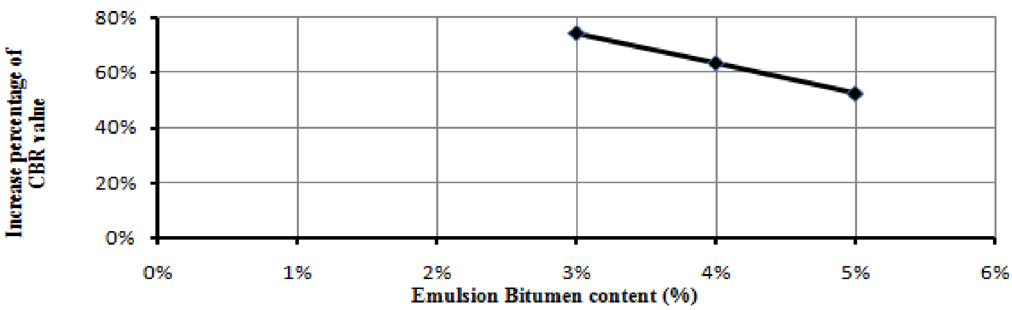

Figure 11: Increase Percentage of CBR Value for Emulsion Bitumen Stabilizer Contents

Figure 12 show increase percentage of CBR value when using Sodium Chloride for stabilization. The rate of increase increased between 3% to 4%, and then decreased between 4% to 5% Sodium Chloride content. This means that 4% is the best content of Sodium Chloride for stabilization with increase percentage of 85%.

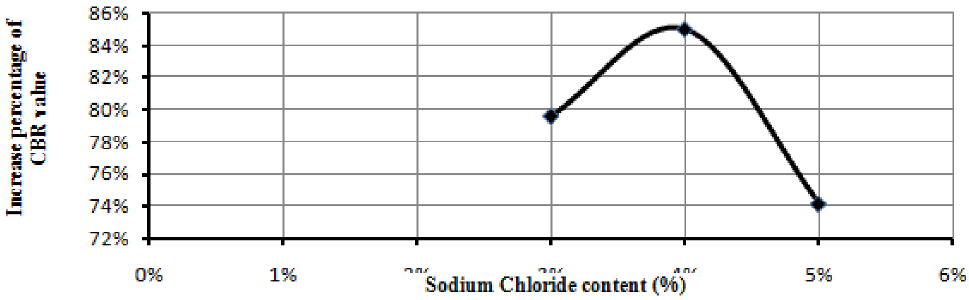

Figure 12: Increase Percentage of CBR Value for Sodium Chloride Stabilizer Contents

CONCLUSIONS

The following provides major conclusions are obtained from the laboratory testing analyses:

- The results presented in this research have confirmed that the addition of lime, emulsion bitumen, or Sodium Chloride to crushed stone affected strength properties as California Bearing Ratio (CBR) and verify requirement.
- The treated material with lime contents of 3%, 4%, and 5% of CBR value at lower than 60% can't be used as a base course. While the contents of 7% can be used for stabilize urban roads and the content of 9% provide a CBR value more than 80%, which permit the stabilized material to be used as a base layer for rural roads.
- Lime content of 9% has the maximum percentage of increase of CBR value of 139.7%. Consequently 9% lime content is the optimum content to increase bearing capacity and reduce the design thickness of layers, and beyond this content the advantages previously gained appear to be lost.
- The use of emulsion bitumen and Sodium Chloride for stabilization of tested material has positive effect on the improvement of strength properties of the treated material, where, the CBR value increased above the value of the natural material and exceed 60% CBR value, but with value less than 80%, this leads to use emulsion bitumen or Sodium Chloride stabilized base for urban roads only.

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