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Evaluating the Effect of Base Course Material Modification on Pavement Performance

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Abstract: **In pavement construction, the mechanical properties of pavement layers have been a crucial concern. Additions such as lime, organic polymer, and sodium chloride have been used as modifier for enhancing the California Bearing Ratio (CBR) value of the natural dolomite soil. This paper proposed regression models relating the CBR values and percentages increase of CBR to dosages of the used additives. Furthermore, the paper tested the performance of the Generalized Concentration Addition (GCA) analytical modelling of CBR enhancement related to using different mixes of additives. Lime-organic polymers mix has utilized to upgrade the CBR. Percentages of enhancement were measured and employed to assess the GCA model results. Results indicated that the highest CBR value of 136% was noticed at 30% of organic polymer. On the other hand, the lowest value of CBR value of 50.2% was noticed at 3% of lime. Furthermore, percentages of 9% lime, 5% sodium chloride, and 10% organic polymer were recommended to improve the CBR value of the base layer. Regression models showed high representativeness owing factors of coefficient of determination (R^2) higher than 0.9. Moreover, GCA results showed good fit to laboratory measured percentage increase of CBR as R^2 higher than 0.8 is gained with acceptable values of Root Mean Square Error (RMSE), Frictional Biases (FB) and Global Mean Biases (MB). Finally, percentages of 9% lime, 5% sodium chloride, and 10% organic polymer saved about 43.6%, 28.5% and 50% of the base layer thickness for the same materials respectively.**

Keywords: **CBR; Base layer thickness; GCA model.**

I. INTRODUCTION AND BACKGROUND

In developing countries, the greatest limitation of providing efficient road networks is the monetary cost. In many cases, available soils for pavement layers are weak and importing new strong materials are costly. In this concern, pavement layers are stabilized for different reasons: modifying the characteristics (strength, stiffness and durability, physical properties) treatment of expansive soils, and to structurally support the pavement. Relating, research work focusing on stabilizing and of pavement base course layers has been a continuous interest [1,2].

Lime has been used broadly to modify mechanical properties of poor fine-grained soils and granular soils [3-6]. Using lime as stabilizer for expensive flexible pavement subgrade soil improves the liquid limit and plastic limit of the soil in addition to upgrading its Californian Bearing Ratio (CBR) from 1% to almost 40%, decreasing the required thickness of the pavement by about 50% and decreases swelling from 4% in untreated soil to 1.20% [2,7]. Lime stabilized clay have been investigated as a highway pavement subgrade and subbase course material [8]. It gained an un-soaked CBR of 36.56% and a 24 hour soaked CBR of 34.23%. For the purpose of pavement construction, physical and mechanical properties of black cotton soil were improved using mixture of lime with fly ash, electric arc furnace dust and stone dust. It provided a valuable improvement in the properties of the black cotton soils [9,10].

Lime also was studied as stabilizer for dominant saline soil containing rich soluble salts used as pavement subgrade [11]. Milburn and Parsons [12] studied the effect of lime on the engineering properties for different types of soil. It was found that using the lime as additive can improve the soil properties such as increasing the strength and enhancing the texture. Negi et al. [13] investigated the impact of using lime on the behavior of soil. They determined the liquid limit, plastic limit and CBR. The result indicated that the addition of lime reduced the plasticity index and increasing the strength of the soil. Bakaiyang et al. [14] examined the efficiency of lime - cement mix on swelling karal-type soils in the North Cameroon region. They determined Atterberg limits, CBR, and unconfined compressive strength for tested mixes. The study concluded that the lime - cement mix enhanced the mechanical properties of the swelling karal-type soils.

For sustainable construction, organic polymers have been receiving more attention as an agent for modifying the characteristics of pavement materials. For an instant, fly ash geopolymer base material introduces unconfined compression strength of 17.1 MPa at 38 ˚C allowing it to be used as a base for flexible pavement [15]. A dosage of about 0.65% of plastic strips in the soil reduces the plasticity index and achieves reduction of the settlements in the soil [16]. In addition, co-polymers were used with soil to improve soil binder compositions to enhance pavement structures [17]. Polymer-stabilized subgrade soil has the advantage of low rutting occurrence opportunities [18]. Thus, it can be utilized for roads carrying high traffic volumes of heavy vehicles. Moreover, It was found that a dosage of 8% acrylic-based waterborne polymer allows samples cured for more than 14 days at 50˚C to enhance their strength by about 150% promoting it to a subgrade and subbase pavement soil [19].

The main aim of this research is twofold: firstly, analyze the influence of using lime, organic polymers, and sodium chloride on the modification of the base course focusing on the enhancement of the CBR values. Secondly, examining the efficiency of using the Generalized Concentration Addition (GCA) mathematical model for simulating the enhancement effect of the base course's CBR related to the usage mixture of additives. Finally, the paper studies the modification benefits in terms of thickness reduction of the

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pavement due to the enhancement of the CBR value of the base course using different individual modifiers.

II. RESEARCH METHODOLGY

This paper studies the benefit of using lime, organic polymers, and sodium chloride as modifiers for the dolomite base course of pavement. Figure 1 represents the research methodology. Three main stages are included. The first stage investigates the enhancement of the base course's CBR value using individual additives. In this stage, the physical and mechanical properties of the base course as well as the additives are shown. In second stage, laboratory tests of CBR modification due to mixture of additives are utilized to validate the employment of GCA model to simulate the modification effect related to using mixture of two additives. Finally, the third stage represents evaluation of the stress-strain modification benefits due to the enhancement of the CBR value of the base course due to using different individual additives in terms of reduction in the pavement thickness.

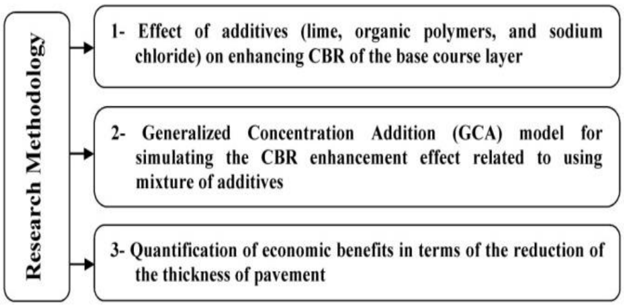

Figure 1. Flowchart of the research methodology

III. MATERIALS PROPERTIES

A. Physical and Mechanical Properties of Natural Soil (Base Course)

The natural soil tested as the base course soil of the pavement is provided from Suez quarries in Suez Governorate, Egypt. This soil is a dolomite soil classified as A-1-b soil and GP (Poorly graded gravels or gravel-sand mixtures, little or no fines) soil according to AASHTO soil classification system and unified soil classification system respectively. The specific gravity and the water content of the soil are 2.6 gm/cm^3 and 1% in order. On the other hand, sieve analysis and other physical properties tests of the base course soil were conducted. The sieve analysis results depicted in Table 1 indicate that the soil is a well graded coarse soil with low fine particle containment. As presented in Table 2, the soil meets ECP [20] specification limits of Los Angeles Abrasion, and water absorption.

In consideration of testing the compaction properties of the natural soil, modified proctor test was performed. Results of the test indicated that the maximum dry density of the base course soil is 2.063 gm/cm3 that exists at the optimum moisture content of 6.55%. On the other hand, to investigate the bearing properties of the natural soil, the CBR test was conducted for a base course soil sample.

Table 1. Sieve analysis results of the base course soil

Sieve Size (mm)	% Passing
50	100
37.5	67.6
25	14.3
22.5	5.5
19	1.6
9.5	0
Pan	0

Table 2. Basic properties of the base course soil

Soil Criteria	% Passing	Specification Limits (ECP)
% Los Angeles Abrasion	43	≤ 40
% Water Absorption	8.3	≤ 10

Results indicated that the design CBR is 35.1%. This result clarifies that such soil is not suitable for being used as a base soil according to ECP [20] specifications as its CBR is lower than 80% and 60% for major roads and minor roads respectively. Therefore, in this research, the CBR value of the dolomite soil is to be improved by testing different additives.

B. Properties of Additives

In this study, three additives were used to modify the CBR value of the natural soil. The study intended to use obtainable additives in the Egyptian market to consider the availability and economical dimension. The lime used in this study is mainly a Calcium hydroxide ($Ca(OH)_2$) hydrated lime produced by Mountain Apex Egyptian company of cement that supplies the product in a white powder form. Properties supplied by the manufacturer are shown in Table 3.

The organic polymer applied in this research is a concentrated organic polymer and enhancer that has a commercial name of EN1, produced by Worldwide Manufacturing Egyptian Company. The product has an effective temperature range e.g. - 22 °C to + 82 °C, and a unit weight of 1.6 g/cm3. Moreover, the product is 100% water soluble and when diluted as directed is safe to use . i.e. they do not affect the PH of the water. EN1 has no poisonous effect and do not contribute to bacteria growth and ecologically meets and exceeds all Environmental Protection Agency (EPA) standards and requirements. So, it is considered environmentally friendly. The Sodium chloride (salts) used is granular NaCl with 96% purity, the specific gravity of which is 2.15.

Table 3. Specifications of the used lime

Property	Value
Content of Calcium Hydroxide $Ca(OH)_2$	85%
Content of Silicon Oxide SiO_2	2%
Content of Magnesium Oxide MgO	1%
Content of Aluminum and Iron Oxide ($Fe_2O_3 – Al_2O_3$)	0.5%
Content of Calcium Carbonates $CaCO_3$	10.5%
Content of Moisture (H_2O)	1%
Passing sieves: Opening Diameter 0.211 mm Opening Diameter 0.90 mm	 3% 6%
Unit Weight	2.211 gm/cm^3

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IV. LABORATORY TESTING PROGRAM

The laboratory testing in this research includes mixing each additive with the base course soil at its optimum moisture content. The mixing composition encloses forming mixtures (at 25 °C) with the different mixing percentages shown in Table 4. For each additive percentage, three samples are prepared. Consequently, the total number of samples is 18, 9, and 9 for lime, sodium chloride, and organic polymer respectively. The lime stabilized mixing dosages is added directly to the soil and mixed effectively. The sodium chloride salt (NaCl) is dissolved in distilled water to obtain a solution of 4% concentration that was used to be mixed with the natural soil.

Regarding organic polymer stabilized base soil, first, the organic polymer is dissolved in water by a ratio of 1 liter of organic polymer: 300 liter of water. Then, the solution is sprayed on the base soil and an effective cold mixing is performed. All samples are compacted in five layers and kept at 25 °C and room humidity for curing period before they are subjected to the CBR test.

Table 4. Mixing percentages for each additive

Additive	Mixing Percentages (% of Weight of Base Course Soil)
Lime	3, 5, 6, 8, 9 and 10%
Sodium Chloride	3, 5 and 6%
Organic Polymer	10, 20 and 30%

Table 5. Effect of different additives on CBR values

Lime		Sodium Chloride		Organic Polymer	
% of Lime	CBR (%)	% of Sodium Chloride	CBR (%)	% of Organic Polymer	CBR (%)
0	35.1	0	35.1	0	35.1
3	50.2	3	60.0	10	92.9
5	51.3	5	63.0	20	117.3
6	56.0	6	62.6	30	136.0
8	66.5				
9	83.9				
10	80.1				

Table 6. Recommended percentage for different additives and improvement percentage in CBR values

Additive	Recommended Percentage of Additive (%)	CBR Value (%)	Improvement (%)
Lime	9	83.9	139.1%
Sodium Chloride	5	63	79.6%
Organic Polymer	10	92.9	164.7%

V. ANALYSIS OF RESULTS

A. Effect of Additives on CBR Values

In this section, the effect of modification of the CBR value of the stabilized soil at different additive dosages is discussed. Results indicated that, for all kinds of additives, the CBR value of the stabilized soil has an upward trend with the increase of the additive dosage. On the other hand, for all kinds of additives, the CBR of the stabilized soil has an optimal beak except for organic polymer which shows a continuous increase in CBR with the increase of organic polymer dosage as shown in Table 5. Throughout dosage ranges, the highest CBR values are 83.9% and 63% which are noticed at 9% lime dosage, and 5% sodium chloride dosage respectively. After these dosages, higher additive parentages are not yielding any more increase in the CBR of the stabilized soil. Regarding organic polymer, a dosage of 10% is sufficient to improve the CBR value of the base layer. Furthermore, from Table 5 it can be noticed that the highest CBR value of 136% was noticed at 30% of organic polymer. On the other hand, the lowest value of CBR value of 50.2% was noticed at 3% of lime. Consequently, the recommended percentage for different additives and improvement percentage in CBR values are presented in Table 6.

Regression models have been developed to simulate the behavior of stabilized soil CBR in response to the additives dosage. Results are shown by Equations (1), (2), and (3). Also, the percentage increase of natural soil CBR caused due to individual additives (ICBR) was modeled by Equations (4), (5), and (6). Where: A_L, A_S, and A_O are the mixing percentages (% of the weight of base soil) of lime, sodium chloride, and organic polymer respectively. All models showed good regression behavior owing to factors of correlation of determination (R^2) higher than 90%.

$$CBR = 35.69e^{8.344A_L} \quad (R^2=0.95) \tag{1}$$

$$CBR = -12125{A_S}^2 + 1177A_S + 35.16 \quad (R^2=0.99) \tag{2}$$

$$CBR = -977.8{A_O}^2 + 620.5A_O + 36.45 \quad (R^2=0.99) \tag{3}$$

$$ICBR = 6983{A_L}^2 + 631.3A_L + 3.883 \quad (R^2=0.94) \tag{4}$$

$$ICBR = -34563{A_S}^2 + 3357A_S + 0.235 \quad (R^2=0.99) \tag{5}$$

$$ICBR = -2787{A_O}^2 + 1769A_O + 3.919 \quad (R^2=0.99) \tag{6}$$

Furthermore, studying the effect of a mixing of additives for modifying the CBR of soil is costly regarding economy and time. Therefore, the GCA analytical model [21-25] is used for predicting the effect of a mix of additives with different mixing dosages. It demonstrates the response shape of mixtures of materials when mixed together considering the effect of each substance and the effect associated with the mixing of different substances. Testing variation of mixes of additives for enhancing the CBR of soils is economically and timely costly. Thus, in this paper, and for the first time, the GCA model is tested against a prediction of soil CBR modification effect using a mixture of stabilizing additives. The general form of the model is as follows:

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$$E = \frac{\sum_{i=1}^{n} \frac{Emax_i * C_i}{C_{E50_i}}}{1+\sum_{i=1}^{n} \frac{C_i}{C_{E50_i}}} \quad (7)$$

Where

E : Effect of the mixture at a specific concentration.

C_i : Concentration of compound i in the mixture.

n : Number of compounds in the mixture.

$Emax_i$: Maximum effect that caused by the compound (i) can produce if it is added individually.

C_{E50_i} : Dosage of compound (i) that produces the compound's half- maximum effect.

To simulate this form in case of base soil CBR modification effect using a mixture of additives, the form in equation (7) is turned into equation (8):

$$\%CBR_M = \frac{\sum_{i=1}^{n} \frac{CBR_{max\ increase\ i} * Co_i}{Co_{CBR_{50max\%\ increase\ i}}}}{1+\sum_{i=1}^{n} \frac{Co_i}{Co_{\%CBR_{50max\ increase\ i}}}} \quad (8)$$

where

$\%CBR_M$: % increase in CBR caused by the mixture (M) at a specific concentration.

Co_i : Concentration of additive i in the mixture.

n : Number of compounds in the mixture.

$CBR_{max\ increase\ i}$: Maximum % increase in CBR that caused the additive (i) if it is added individually.

$Co_{CBR_{50max\ increase\ i}}$: Concentration of additive (i) that causes the additive's 50% of $CBR_{max\ \%increase\ i}$.

The performance of the formula in Equation (8) is tested against laboratory real observed data of CBR modification using mixing of additives. In the laboratory, the investigated samples of mixing two additives with different mixing percentages have been prepared to measure the natural soil's CBR modification due to using the mixture. Based on the views of a group of experts, eleven investigated mixes have been prepared for lime - sodium chloride mixture with the mixing percentages shown in Table 7. Each of them has been added to the natural soil with a dosage of 5 % of the weight of base course soil. Then, samples have been cured and the CBR of each sample is measured and the increase percentage of CBR is derived. On the other hand, the GCA formula in Equation (8) has been applied to the investigated samples and the estimated percentage increase of CBR considering the maximum percentage increase in CBR caused by the additives if used individually ($CBR_{max\ increase\ i}$), and the dosage of additive (i) that causes the additive's 50% of $CBR_{max\ \%increase\ i}$, i.e. ($Co_{CBR_{50max\ increase\ i}}$) at the dosage of 5% as presented in Table 8.

For the lime - sodium chloride mix combinations, Figure 2 clearly shows a good fit between the GCA modeled percentage increase of CBR and laboratory measured increasing percentage of CBR as a good correlation of determination (R^2) is gained (higher than 0.8). Moreover, the performance indicators in Table 9 provide the following facts:

GCA model has a relatively small Mean Biases (MB); (-0.5 for lime - sodium chloride mix). This value represents small average of errors in estimating the percentage increase of CBR.

GCA model introduces percentage increase of CBR that are comparable to laboratory measured increase percentage of CBR as the Root Mean Square Error (RMSE) is small; (2.7 for lime – sodium chloride mix). This also indicates that GCA model is able to describe the increase percentage of CBR related to a mix of additives as a function of the effect of individual additives.

GCA model presents acceptable value of Frictional Biases (FB); (0.01 for lime - sodium chloride mix). Therefore, the overall performance of the model is adequate since the performance of the model is considered acceptable if -0.7<FB<0.7 [26].

Where:

C_p = Predicted (modeled using GCA) increase of CBR concentration (%);

C_m = Measured (in laboratory) of CBR concentration (%);

N = Number of observations; and

$\overline{C_p}$, $\overline{C_m}$ = Average values of C_p and C_m respectively.

Table 7. Percentage of additives in lime - sodium chloride tested mixtures

Lime – Sodium Chloride Mix	
% Lime in Mix	% Sodium Chloride in Mix
10	10, 20, 30, and 40
20	10
30	10
40	10
50	40
60	30
70	20
80	10

Table 8. Increase percentage of CBR for different additives at 5% percentage

Additive (*i*)	Lime	Sodium chloride
$CBR_{max\ increase\ i}$	46.3%	79.6%
$Co_{CBR_{50max\ increase\ i}}$	2.41%	1.37%

Table 9. Statistical indicators of the performance of GCA model for percentage increase predicting of CBR

Statistical Indicator	Values for Lime - Sodium Chloride Mix
Root Mean Square Error (RMSE) $= \sqrt{\frac{(C_p - C_m)^2}{N-1}}$	2.7
Frictional Biases (FB) $= 2\left(\frac{\overline{C_m} - \overline{C_p}}{\overline{C_m} + \overline{C_p}}\right)$	0.01
Global Mean Biases (MB) $= \overline{C_p} - \overline{C_m}$	-0.5

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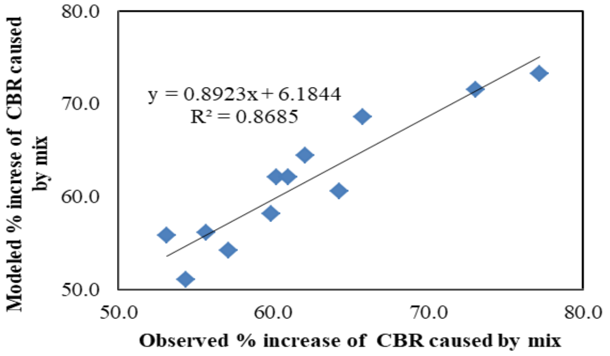

Figure 2. Modeled and measured increase percentages of CBR for lime - sodium chloride mix

B. Effect of Additives on the Reduction in the Pavement Thickness

The pavement section used in this study to identify the benefit of modification of the base course layer in terms of thickness reduction is based on a real section from an Egyptian field experiment. The pavement consists of:

- 120 mm thickness of asphalt surface layer of 0.33 Poisson's ratio;
- A base course layer has a thickness of 600 mm with 0.38 Poisson's ratio; and
- Silty-clay subgrade soil layer with the assumption of infinite thickness with a modulus of elasticity of 21 MPa and 0.43 Poisson's ratio.

The modeling conditions considered are:

- Loading conditions of a single axel load with 40 KN wheel load (single tire) and contact radius of 15 cm;
- Service life of section with modified base course layer is equal to the service life of section with unmodified base course layer; and
- Vertical compression strain is measured at the top of the subgrade layer.

KENPAVE software is able to determine the strain values at every position of the pavement system [27]. It is exploited to represent the vertical compressive strain for both unmodified and modified base course layer in the pavement. For the un-stabilized base course material, a pavement with 60 cm base course layer is considered for test, while for the stabilized base course layer, various thickness were tested for each stabilization material as shown in Figures from 3 to 5. It is found that for the vertical compressive strain at the top of the subgrade layer for pavement with unmodified base course is 0.012 mm. At this value of vertical comprehensive strength at the top of the subgrade layer, the required base course layer thickness will be almost 35.7 cm, 42.86 cm, and 30 cm for pavement with modified base course layer using 9% of lime, 5% sodium chloride and 10% organic polymer respectively.

It is also indicated that, assuming the same service life, the modified base course layer with 9% of lime, 5% sodium chloride and 10% organic polymer can save pavement layer thickness by 43.6%, 25.8% and 50%, respectively. It is worthy to mention here that these findings can be useful as design aids to identify the suitable base course layer thickness for each type of modifiers considering the vertical compressive strain of 0.012 mm at the top of subgrade layer as a key value.

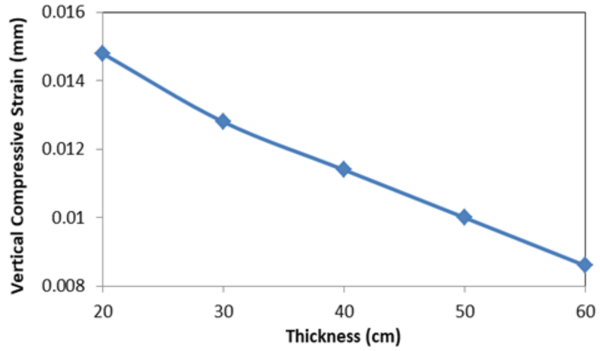

Figure 3. Relationship between the thickness of base course layer and vertical compressive strain at the top of subgrade layer (9% lime)

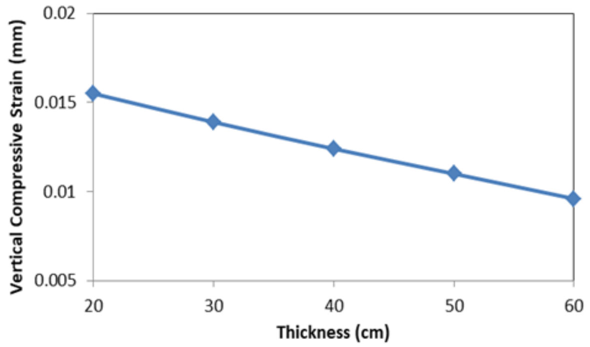

Figure 4. Relationship between the thickness of base course layer and vertical compressive strain at the top of subgrade layer (5% sodium chloride)

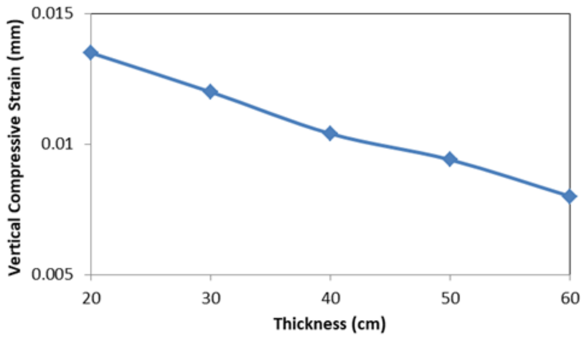

Figure 5. Relationship between the thickness of base course layer and vertical compressive strain at the top of subgrade layer (10% organic polymer)

VI. CONCLUSIONS

This paper evaluated the effect of using lime, organic polymers, and sodium chloride on the modification of the base course based on CBR values. Also, it introduced regression models to represent CBR and percentage CBR increase related to using dosages of lime, organic polymers and sodium chloride as soil modifiers. The GCA analytical model has been tested for its ability to represent the enhancement of CBR related to using different mixes of

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additives. Pavement base layer thickness reductions due to using different individual additives were investigated. After analyzing the results, the following conclusions can be drawn:

1. All types of used additives increase the strength of base course soil in terms of CBR value.
2. Using 9% lime, 5% sodium chloride, and 10% organic polymer increased CBR value of base layer by 139.1%, 79.6%, and 164.7% respectively.
3. A 30% by weight of organic polymer exhibited the highest CBR enhancement effect (288%). On the other hand, the lowest percentage increase of CBR (43.1%) was noticed at a percentage of 3% of lime.
4. GCA results showed a good fit of the model results to laboratory measured increasing percentage of CBR values as R^2 of higher than 80% is gained with acceptable values of RMSE, FB, and MB.
5. Using 9% lime, 5% sodium chloride, and 10% organic polymer saved about 43.6%, 28.5%, and 50% of the base layer thickness for the same materials respectively.

Using such additives open the door to enhancing the strength of materials and saving in layer thicknesses for pavement system. This study is limited to performing CBR test on dolomite soil. A future extension of this research should be conducted on various types of soils using different tests such as unconfined compression test and triaxial compression test.

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Conflicts of Interest: The authors declare that there is no conflict of interest.

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