Third International Conference on Construction in the 21st Century (CITC-III)
"Advancing Engineering, Management and Technology"
15-17, September 2005, Athens

Effect Of Soil Stabilization on California Bearing Ratio and Pavement Construction Cost

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Abstract

The potential use of hydrated lime and Portland cement as a soil stabilizing admixture and the impact of stabilization on the California Bearing Ratio (CBR) and pavement construction cost were evaluated in this study. Two soil samples obtained from two locations in the northern part of Jordan (East of Irbid and Jordan University of Science and Technology (J.U.S.T.) campus) were evaluated in this study. Two types of stabilizing agent, lime and Portland cement, were added at different percentages by weight of dry soil. After 28 days of curing, the specimens were soaked in water for four days and drained for 15 minutes, then the California Bearing Ratio (CBR) test was conducted. The correlation between CBR and unconfined compressive strength for Irbid soil stabilized by lime was evaluated. This study also covers the characterization of the compaction behavior of stabilized soils.

The results indicated that the CBR value, for the two evaluated soils, increased as the percentage of lime increased to an optimum level of 6%, after which a decrease in the CBR was noted. On the other hand, the CBR value continued to increase as the amount of cement added to the soils increased. In contrast to the CBR results, Unconfined Compressive Strength of Irbid soil stabilized by lime continued to increase regardless of the amount of lime. For the two evaluated soils, Portland cement was found to be much more effective in improving the soil CBR value compared to that of the lime stabilizing admixture. Adding 2% of cement increased the CBR by 7.3 and 8.1 times for Irbid and J.U.S.T. soils, respectively. While adding 3% of lime increased the CBR value by 1.4 and 1.6 times for Irbid and J.U.S.T. soils, respectively. Increasing the amount of stabilizing materials caused a drop in the maximum dry density and a slight rise in the optimum moisture content of both soils.

Keywords

stabilization, admixtures, lime, cement, soil

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1. Introduction

Soil stabilization is the alteration of the property of soil to improve engineering performance, such as strength, stiffness, compressibility, permeability, workability, and sensitivity. In many cases, stabilization of the soil is needed in order to obtain larger values of unconfined compressive strength and the California Bearing Ratio so that a more economical design, due to a reduction in base thickness, may be achieved.

Lime as a soil stabilizer is among the oldest stabilizing agents for road construction, dating back to the Romans. Lime reduces the volume changes and the plasticity of highly plastic soils (El-Rawi, 1967). Lime causes an increase in the strength of clay soil. Also, Portland cement is widely used in soil stabilization. Cement causes an increase in soil strength and durability, and minimizes moisture variations and swelling potential (Yoder, 1957). In 1998, approx. 1.3 million m^3 of soil was stabilized in the United Kingdom, while in 2002, more than 100,000 m^3 of soil was stabilized in constructing shopping areas, airplane taxiways, and factories in Ireland. Soil stabilization is even more popular in the U.S.A., where more than 40 million m^3 was stabilized (Clogrennane Lime Limited Soil Stabilization, 2004).

Soil-cement has been increasingly used as a satisfactory base or sub-base, and subgrade for modern highway and airfield pavements. Cement has become the most utilized stabilizing admixture in constructing roads, especially when the moisture content of the subgrade is very high. In laboratory different techniques can be used to evaluate, the effect of soil stabilization or improvement of its properties, which include Unconfined Compressive Strength, Triaxial Compressive Strength, and the California Bearing Ratio.

Prabakar *et al*. (2004) investigated the usefulness of fly ash as a soil admixture to improve the engineering properties of soil. Fly ash was added to soil using different percentages ranging from 9% to 46% by weight of dry soil. The results of the study indicated significant improvement in the CBR, shear strength parameters, and settlement behavior.

The effect of five stabilizing agents including limestone dust, lime, marl, emulsified asphalt, and cement on the strength of arid, saline, coarse grained soil was evaluated by Al-Amoudi *et al.* (1996). The study results indicated that marl and emulsified asphalt has no effect on the soil strength, while limestone dust has marginal effect on the soil strength. On the other hand, the addition of 10% lime or cement increased the strength by 22 times.

The bearing strength, durability, and structural reliability of pavement resting on subgrade stabilized by different types of admixtures were evaluated by Hopkins *et al.* (2002). The CBR was performed on 40 road sections constructed on unstabilized subgrade or subgrades stabilized with different types of stabilizing agents. The results indicated that the CBR values of subgrades stabilized by hydrated lime, Portland cement, and a combination of hydrated lime and Portland cement are in the range of 12 to 30 times that of unstabilized subgrade. In another study by Osula (1996), the effect of using lime as a soil stabilizer was compared to that of cement. The results indicated that lime is marginally better than cement.

An investigation to evaluate the improvement of different types of soil for the purpose of pavement construction was performed by mixing Sahu (2001). The soils were mixed with fly ash. The soil-fly ash mixes were cured for 7 days, then soaked in water for 4 days, before the (CBR) were determined. The gain in CBR found to be maximum in sandy soils and minimum in clayey soil. In general, stabilizing the soil using fly ash found to provide economic solution for road construction and reduce the amount of dumping fly ash as waste materials.

Alsharky (1994) evaluated the effect of cement on swelling characteristics of different types of unstabilized clays and cement stabilized clays, with different percentages of cement at different curing times. The results of this study indicated that as the curing time increased, the volume of cementation material formed from the hydration of cement increased, so the potential for swelling was reduced. Also, the swell potential decreased steadily as the amount of added cement increased up to 2 %, beyond which adding more cement would have no significant effect on reducing the swell potential.

The unconfined compressive strength and modulus of elasticity of Irbid soil stabilized by lime have been evaluated by Alawneh (1989). The study results indicated a substantial increase in unconfined compressive strength, a reduction in soil compressibility, an increase in compressive strength, and more resistance to expansion and volume change of soil as the lime content increased.

A study on the effect of soil properties on pavement failures was performed by Jegede (2000). The study includes visual evaluation of pavement failures and extensive investigation of subgrade soil properties. The results of the study indicated that there is a need to stabilie the subgrade soil inorder to improve the pavement performance and extend its life.

2. Objectives

This study aims to evaluate the effect of soil stabilization on the CBR value, and assess the usefulness of hydrated lime and Portland cement as a soil stabilizing admixture. Another objective of the study was evaluation the relationship between the CBR and unconfined compressive strength of Irbid soil stabilized with lime.

3. Tested Materials

3.1 Soil

The soil samples evaluated in this study were obtained from two sites located in the northern part of Jordan. The first site is located in the eastern part of Irbid, Jordan, while the second one was on the campus of Jordan University of Science and Technology (J.U.S.T.). The soils of these sites were studied previously for the physical properties including shear strength and compaction behavior (Alawneh, 1989, and Alsharky, 1994). The two evaluated soils were classified as poor subgrade. The disturbed samples were obtained from a depth of 0.5 m to 1.5 m below ground surface. The physical properties of the evaluated soils are summarized in Table 1**.**

Table 1 Physical Properties of Evaluated Soils

	Liquid Limit	Plastic Limit	Plasticity Index	Dry Density	Particle Size (%)		
					Sand	Silt	Clay
Irbid soil	64	31	33	2.67	7	38	55
J.U.S.T soil	52	27	25	2.64	**16**	33	51

3.2 Stabilizing Materials

Two types of stabilizing materials were evaluated in this study; hydrated lime and Portland cement. Hydrated lime is known as calcium oxide (CaO) but the commonly used term includes forms of quick lime and hydrated lime, which are oxides and hydroxides of calcium-magnesium. The type of lime used in this research is commercial hydrated lime manufactured according to Jordanian specifications (JSS/153/1980) summarized in Table 2. Ordinary Type 1 Portland cement was used as a stabilizing admixture for both soils evaluated in this study. In Jordan two types of cement can be used for stabilization, ordinary Portland cement and pozzolanic Portland cement. One difference between the two types is that ordinary cement has a higher early strength than the pozzolanic Portland cement.

4. Laboratory Tests

The soil samples obtained were dried and crushed with a plastic hammer. The soil portion finer than a 19 mm sieve size was used, then the soil was mixed with the suitable amount of stabilizing agent until a more homogenous was obtain mix that was used throughout the testing program. The treated soil was placed in bags and stored for later use in the CBR determination. Light weight (standard Proctor) compaction tests were carried out to determine the optimum moisture content and maximum dry density for all cement-soil and lime-soil mixtures. The resulting optimum water content and maximum dry density obtained from compaction tests are summarized in Tables 3 and 4 for lime and cement stabilized soil, respectively.

Table 2 Properties of Hydrated Lime Used in Stabilization

Property	Specification
CaO + MgO (% by weight)	Less than 65
MgO (% by weight)	Less than 4
CO_2 (% by weight)	Less than 6
Insoluble Material (% by weight)	Less than 1.0
Fineness	Not more than 10.0 % by weight should be retained on a sieve with 0.09 mm opening size. Not more than 5% by weight should be retained on a sieve with 0.25 mm opening size.

Cylindrical samples were prepared at their respective stabilizing material and optimum water content. The samples were wrapped with polyethylene bags and placed in a curing room for 28 days at 100% humidity and a temperature of 23 $_oC$. After curing, the specimens were soaked in water for four days and drained for 15 minutes; then the California Bearing Ratio (CBR) tests were conducted.

Table 3 Optimum Water Content of the Two Evaluated Soils at Different Hydrated Lime Contents

LIME %	0	3	6	9
Irbid Soil OPTIMUM WATER CONTENT (%)	29.1	30.0	30.5	31.2
J.U.S.T OPTIMUM WATER CONTENT (%)	20.9	22.3	23.1	23.5

Table 4 Optimum Water Content of the Two Evaluated Soils at Different Portland Cement Contents

CEMENT %	0	1	2	4

Irbid Soil OPTIMUM WATER CONTENT (%)	29.1	30.2	31.0	31.5
J.U.S.T Soil OPTIMUM WATER CONTENT (%)	20.9	22.7	23.4	24.7

To observe the effect of lime and cement stabilization on the natural soils, the soils were mixed with either hydrated lime (0, 3, 6, and 9 percent by weight of dry soil) or Portland cement (0, 1, 2, 4 percent by weight of dry soil). Although the CBR test might not be the best test to evaluate soil stabilization it was used in this study since it is the main test used to evaluated soil and aggregate strength for the purpose of pavement design. Also, submerging the CBR sample in water simulates the effect of layer saturation in the field. Both the hydrated lime and Portland cement treated soils were tested for CBR. The results of these tests, summarized in Tables 5 and 6, were analyzed to evaluate the effect of stabilizing materials on soils CBR values.

Table 5 Effect of Lime Content on CBR of Evaluated Soils

	Lime admixture (%)	0			3			6			9		
Irbid Soil	**CBR**	1.8	1.3	1.5	2.3	2.0	2.1	2.0	2.5	2.5	2.2	2.4	2.1
	Average CBR	1.5			2.1			2.3			2.2		
J.U.S.T Soil	**CBR**	1.9	1.7	1.8	2.8	3.2	2.3	3.9	3.1	2.7	2.2	1.4	1.5
	Average CBR	1.8			2.8			3.2			1.7		

Table 6 Effect of Cement Content on CBR of Evaluated Soils

	Cement admixture (%)	0			1			2			4		
Irbid Soil	**CBR**	1.8	1.3	1.5	2.5	2.9	2.8	11.6	10.6	10.4	26.4	28.5	20.7
	Average CBR	1.5			2.7			10.9			25.2		
J.U.S.T Soil	**CBR**	1.9	1.7	1.8	3.4	4.4	3.6	14.9	14.5	14.4	49.8	43.6	36.8
	Average CBR	1.8			3.8			14.6			43.4		

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5. Test Results And Discussion On Laboratory Tests

The test results indicate that the two types of soils are classified as A-7 according to AASHTO soil classification. Figures 1 through 4 show the variations in the maximum dry density and optimum moisture content with the increase of stabilizing admixtures. These figures indicate that the addition of stabilizing material causes a reduction in the maximum dry density and a slight increase in the optimum moisture content. This drop in maximum dry density is caused by flocculation of clay particles expected to be caused by cation exchange and the replacement of clay particles in a given volume by particles of the stabilizing admixture. For lime stabilized soil, the rate of drop in the maximum dry density was high at low stabilizing admixture content, then this rate of drop slowed down as the admixture content increased. The slight increase in optimum moisture content with the increase of stabilizing admixture might be caused by the need of additional water to hydrate the stabilizing admixture, the high affinity of stabilizing admixtures for water, and the pozzolanic reaction between clay and the stabilizing admixture. It can be noticed that for the same amount of increase in the stabilizing agent, the increase in the amount of water to achieve the optimum moisture content at high amount of stabilizing admixture is less than that required at small amounts of stabilizing admixture. This might be explained by the reduction in the specific surface of the newly formed cemented particles as a small amount of stabilizing agent added.

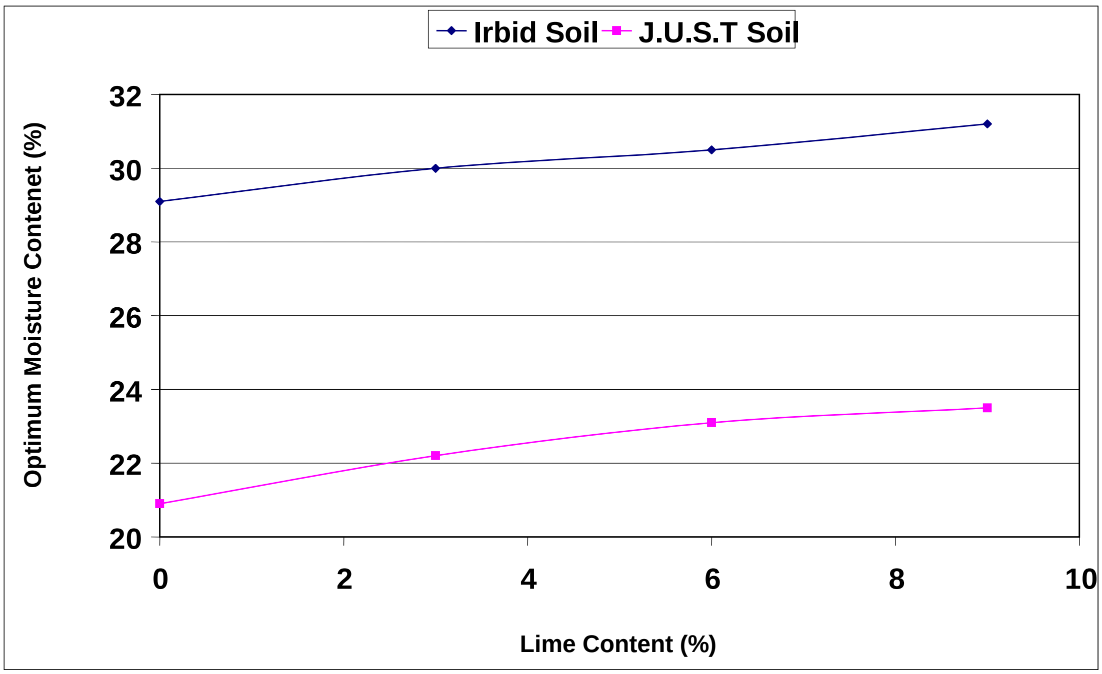

Figure 1 Soil Optimum Moisture Content at Different Contents of Hydrated lime

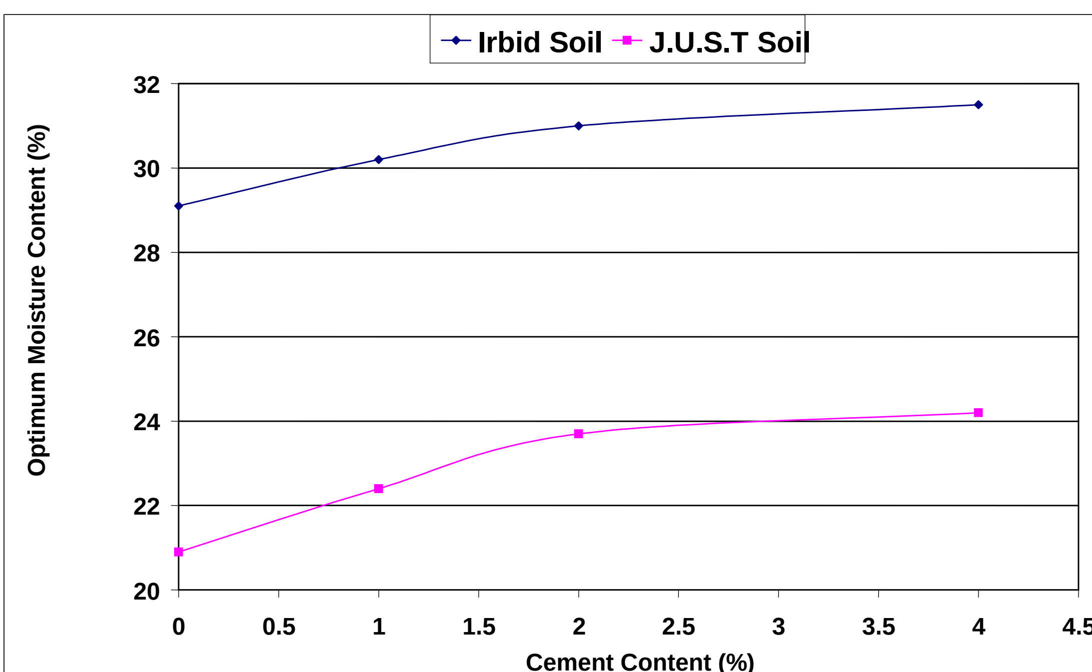

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Figure 2 Soil of Optimum Moisture Content at Different Portland Cement Contents

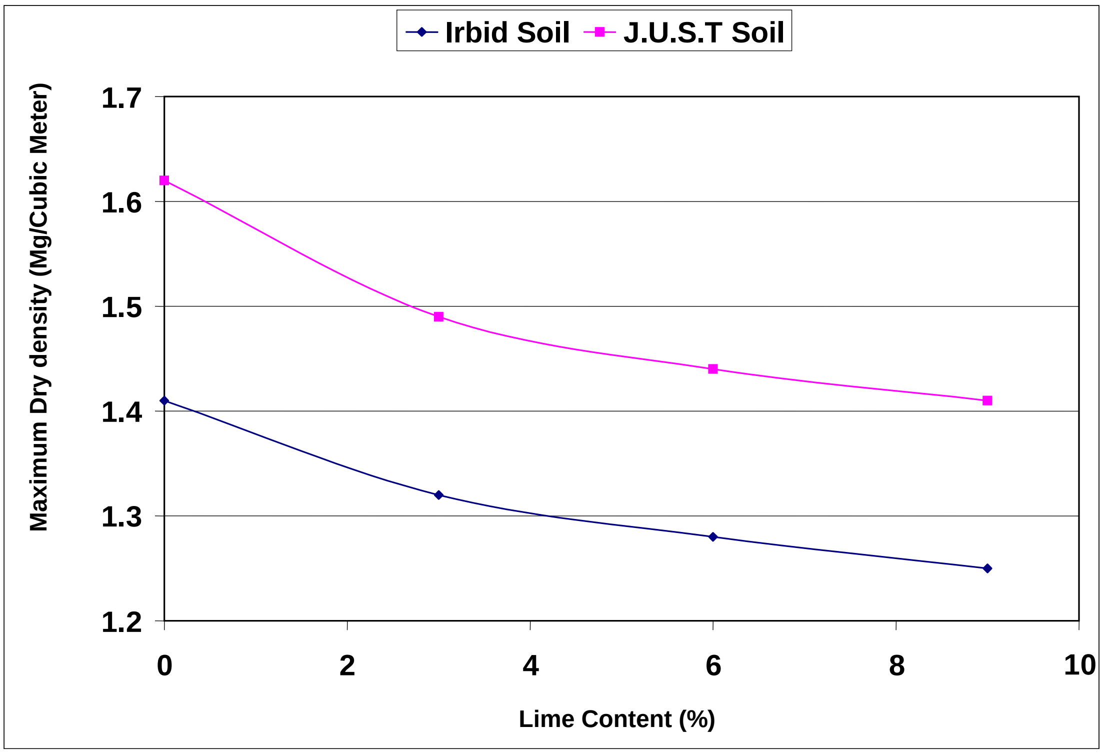

Figure 3 Maximum Dry Density of Soils Mixtures at Different Contents Lime

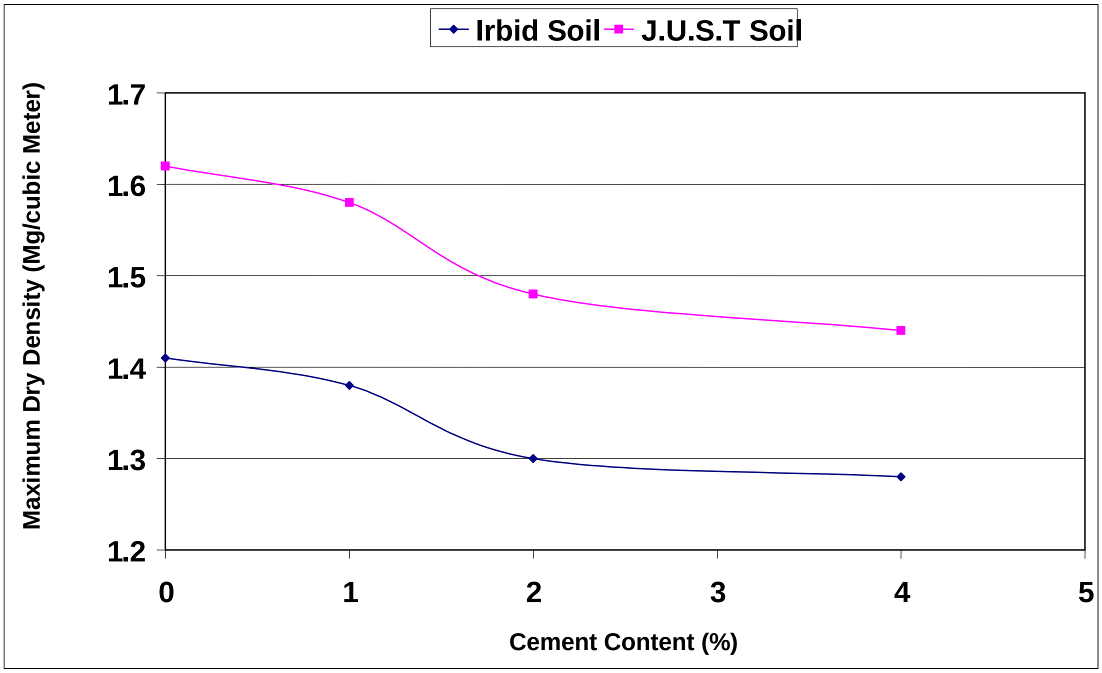

Figure 4 Maximum Dry Density of Soils Mixtures at Different Content of Portland Cement

The variations in the CBR values for the two evaluated soils mixed with different amounts of hydrated lime and Portland cement are summarized in Tables 5 and 6 and Figures 5 and 6. The effect of lime content on the CBR values after 28 days of curing for the two soils indicated that the two soils are slightly affected by adding lime. The results indicated that the CBR value, for the two evaluated soils, increased as the percentage of lime increased to an optimum level of 6% after which a reduction in the CBR value was noted. Similar results, but with less optimum lime content, have been observed by different researchers (Okagbue and Yakuba, 2000; Osula, 1991, and Thompson, 1966). Different researchers explained the effect of adding lime to the soil in different ways including cation exchange, formation of bonds between clay particles, flocculation, pozzolanic reaction, and carbonation. The first three causes occur rapidly (short-term reaction) while the rest are long-term reactions.

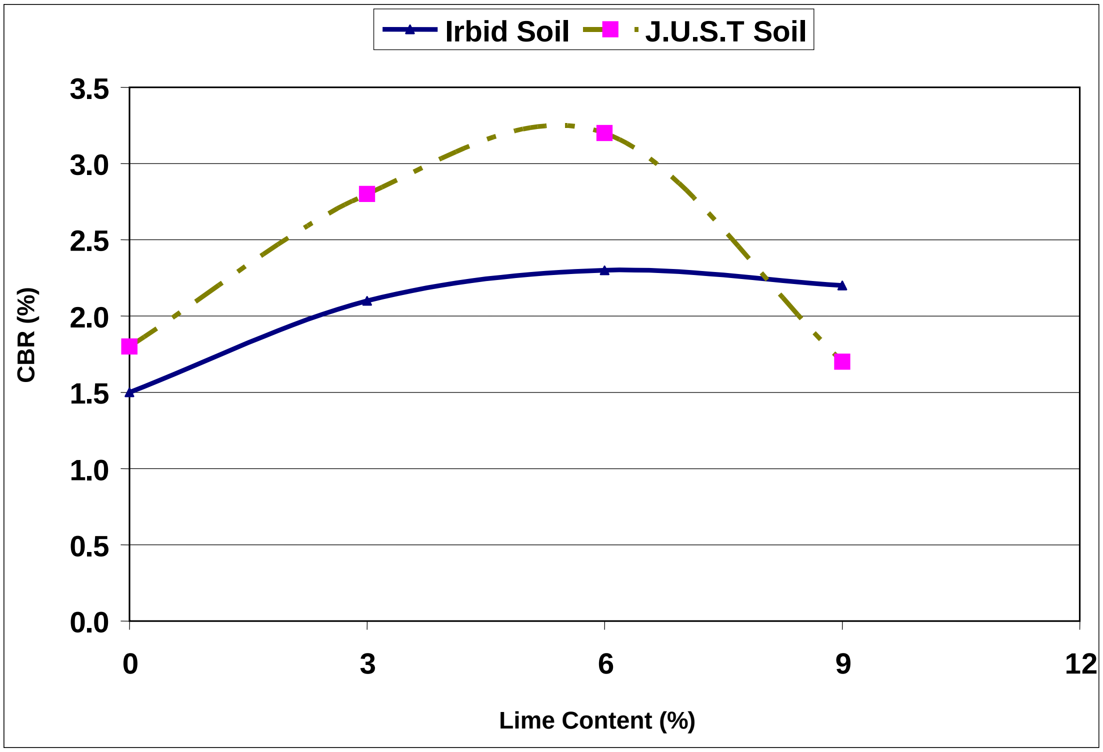

Figure 5 Effect of Lime Content on California Bearing Ratio of Evaluated Soils

On the other hand, the CBR value continued to increase as the amount of Portland cement added to the soils increased. For the two evaluated soils, the effect of adding Portland cement was found to be much more effective in improving the soil CBR value compared to that of adding the lime stabilizing agent. Adding 2% of cement increased the CBR value by 7.3 and 8.1 times for Irbid and J.U.S.T. soils, respectively. While adding 3% of lime increased the CBR value by 1.5 and 1.8 times for Irbid and J.U.S.T. soils, respectively. The above mentioned results lead to the fact that the effect of using lime as stabilizing admixture on J.U.S.T soil was more significant than that on Irbid soil, however the difference in the effect of lime admixture on the two soils was relatively small. The maximum value of the CBR for Irbid soil stabilized with lime was found to be 2.3. While the maximum CBR value for J.U.S.T soil

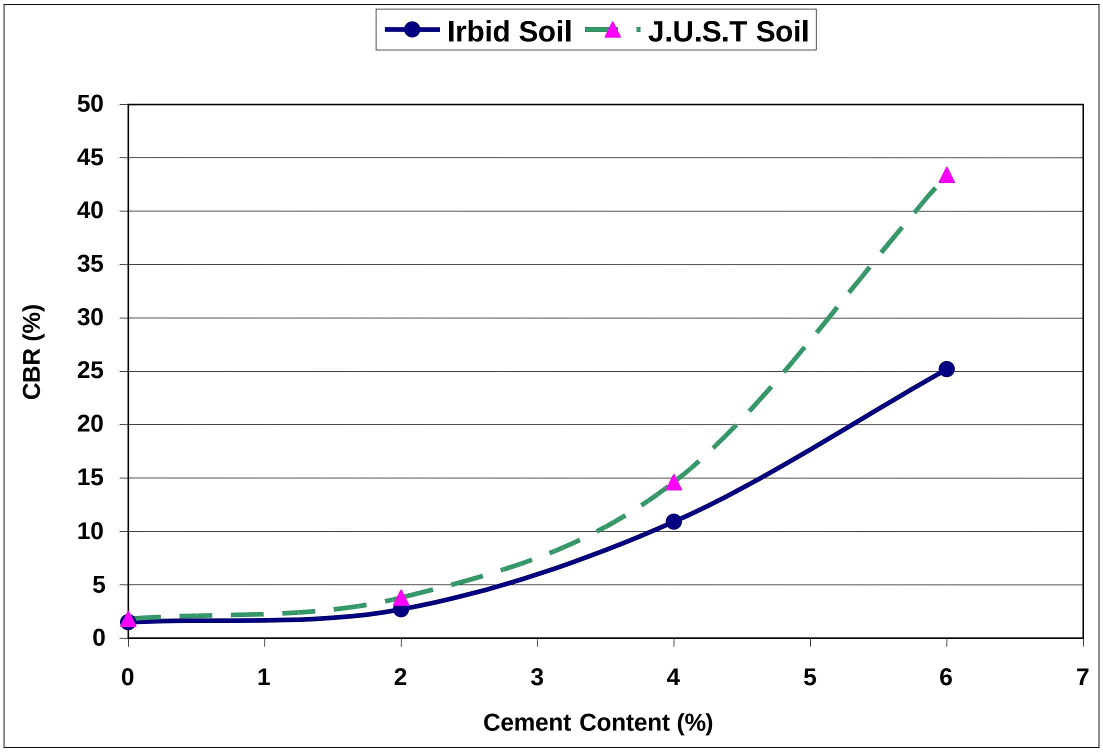

Figure 6 Effect of Portland Cement Content on CBR of Evaluated Soils

stabilized with lime was 3.2. This can be explained by the fact that Irbid soil contains more organic matter which inhibits the cementation action of part of the added lime. So, not all added lime was used in cementing the clay particles. The increase in the CBR value can be explained by the changes in structure and composition, which takes into account new mineral formation due to lime treatment. Based on literature, lime is more efficient when used in granular materials and lean (inorganic) clays. The addition of lime to soils under evaluation resulted in a decrease in soil density, changes of the plasticity properties and an insignificant increase of its strength. Unconfined compressive strength of Irbid soils stabilized by lime continued to increase regardless the amount of lime added as shown in Figure 7.

On the other hand, the CBR value continued to increase as the amount of Portland cement added to the soils increased. For the two evaluated soils, the effect of adding Portland cement was found to be much more effective in improving the soil CBR value compared to that of adding the lime stabilizing agent. Adding 2% of cement increased the CBR value by 7.3 and 8.1 times for Irbid and J.U.S.T. soils, respectively. While adding 3% of lime increased the CBR value by 1.5 and 1.8 times for Irbid and J.U.S.T. soils, respectively. The above mentioned results lead to the fact that the effect of using lime as stabilizing admixture on J.U.S.T soil was more significant than that on Irbid soil, however the difference in the effect of lime admixture on the two soils was relatively small. The maximum value of the CBR for Irbid soil stabilized with lime was found to be 2.3. While the maximum CBR value for J.U.S.T soil stabilized with lime was 3.2. This can be explained by the fact that Irbid soil contains more organic matter which inhibits the cementation action of part of the added lime. So, not all added lime was used in cementing the clay particles. The increase in the CBR value can be explained by the changes in structure and composition, which takes into account new mineral formation due to lime treatment. Based on literature, lime is more efficient when used in granular materials and lean (inorganic) clays. The addition of lime to soils under evaluation resulted in a decrease in soil density, changes of the plasticity properties and an insignificant increase of its strength. Unconfined compressive strength of Irbid soils stabilized by lime continued to increase regardless the amount of lime added as shown in Figure 7.

The relationship between the CBR values in this study and unconfined compressive strength of Irbid soil stabilized by lime reported by Alawneh (1989) is shown in figure 8. Based on this figure it can be seen that no relationship between CBR and unconfined compressive strength. The CBR values continued to increase as the amount of admixture increased up to 6% after which the CBR the tended to drop as the amount of lime increased; while the unconfined compressive strength continued to increase with the increase of stabilizing admixtures. This might be caused by soaking the CBR samples that might caused destroying part of the stabilization structure. This is especially true at high lime content. .

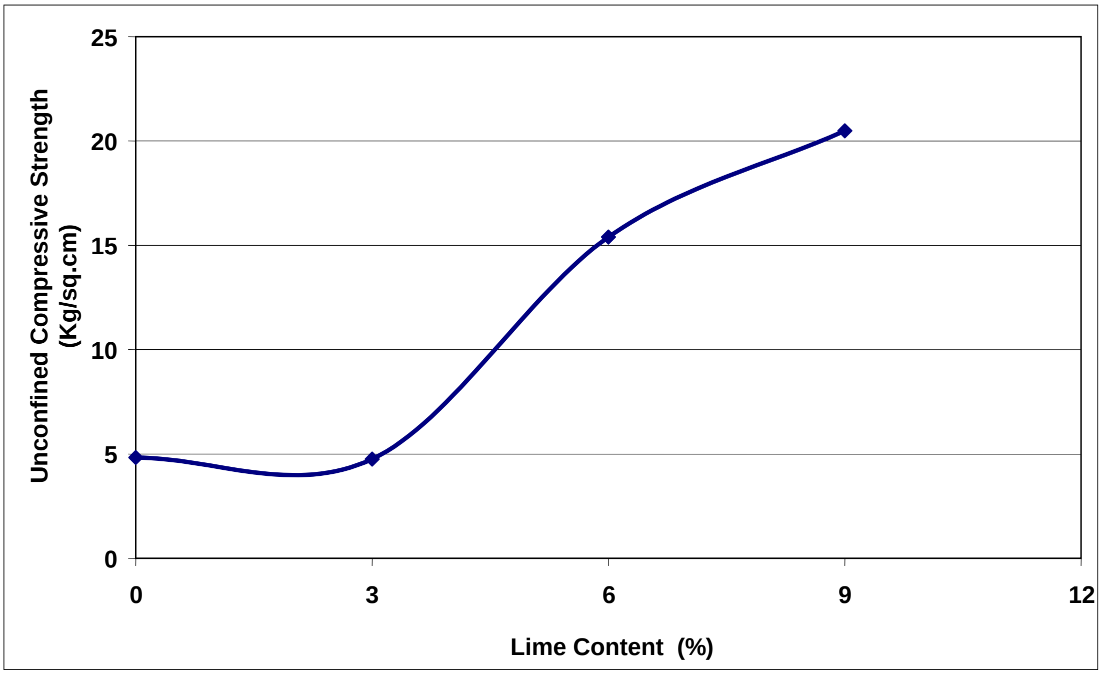

Figure 7 Unconfined Compressive Strength of Irbid Soil at Different Percentages of Hydrated Lime (Alawneh, 1989)

Moreover, the study results indicated that a small amount of Portland cement (1% by weight of dry soil) does not significantly affect the CBR and unconfined compressive strength values. However, larger amounts of this stabilizing admixtures significantly improve the soils CBR and unconfined compressive strength values. It should be noted that some of the above results might be limited only to the two types of soils evaluated in this study.

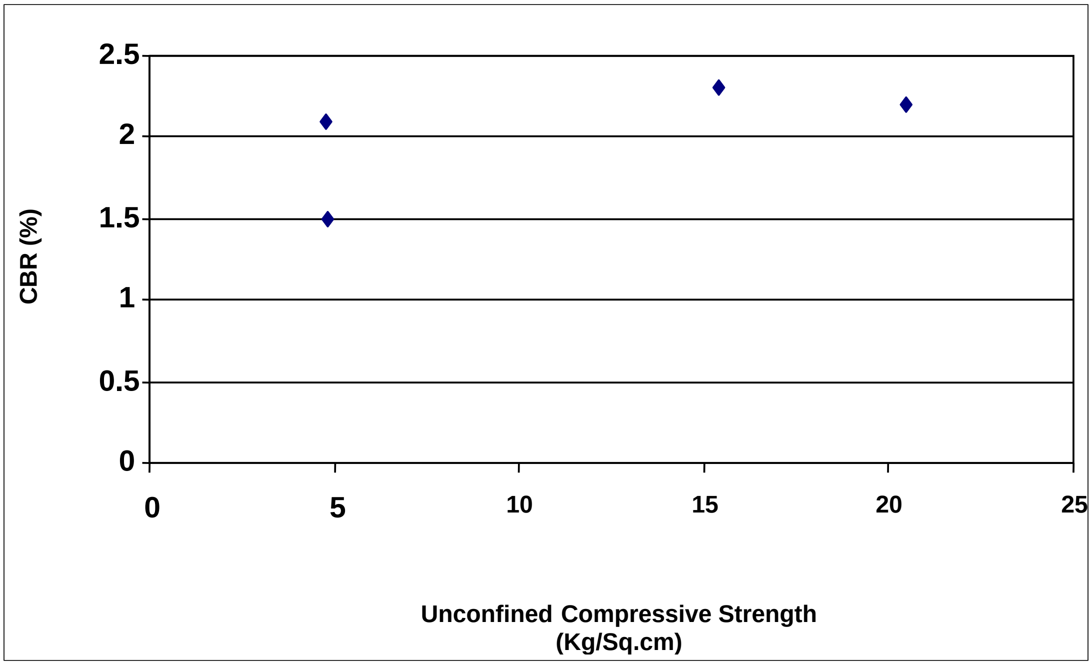

Figure 8 Unconfined Compressive Strength Versus CBR for Irbid Soil

6. Economic Impact of Pavement Subgrade Stabilization

In this section, the economic impact of stabilization of the pavement subgrade soil was evaluated. This was achieved by evaluating three design alternatives including: flexible pavement with natural subgrade soil (unstabilized subgrade), flexible pavement with subgrade soil stabilized using 6% lime and Flexible pavement with subgrade soil stabilized using 4% cement.

The AASHTO pavement design method was used to design the three alternatives to achieve the design requirements shown in table 7. Figure 9 shows the resulting cross-sections of the three designed alternatives. Based on this figure, it can be seen that the subbase layers thicknesses were reduced significantly due to subgrade soil stabilization for pavement sections with lime stabilized subgrade. The resulting subbase thickness was small so it was combined with base. While the design results for pavement sections with cement stabilized soil indicated that there is no need for base and subbase from structural point of view, however a little increase in the HMA thickness was needed.

Table 7 Design Requirement for all Evaluated Alternatives

Design requirement	Magnitude
Standard Axle repetitions	$5 * 10^{6}$
Initial serviceability index	4.5
Terminal serviceability index	2.5
Reliability	95%
Standard deviation	0.35

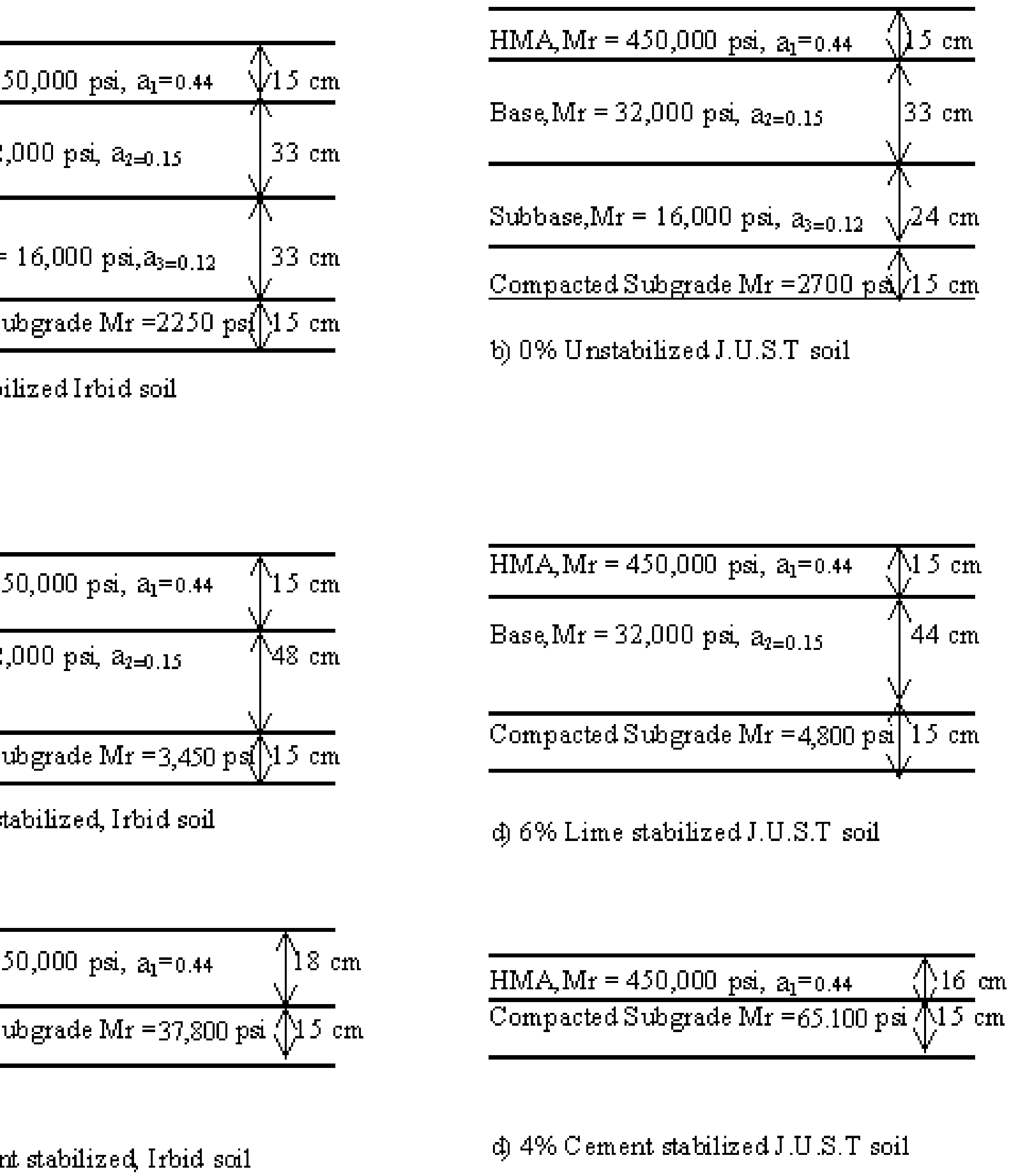

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Figure 9 Pavement Layers Thickness for Unstabilized soils, 6% Lime, and 4% Cement Stabilized Soils

In order to evaluate the economic impact of reduction in the required layers of thickness caused by stabilization of subgrade soil, a simple economic analysis was performed. This economic analysis only considered the cost of the construction of pavement layers, since other costs such as investigation and design, earth works, drainage system, administration will be similar for different alternatives. The maintenance cost was assumed to be the same, although the pavements with stabilized subgrade are expected to have less maintenance cost due to a better performance caused by higher pavement resistance to loads and environmental effect.

The unit cost, including materials and construction, per unit volume for pavement layers were calculated based in highway tenders offered in Jordan in 2004. The calculated unit costs for different pavement layers are summarized in table 8. Based on cost in this table and cross sections shown in Figure 9, the cost of constructing one square meter pavement on Irbid soil was \$14.00, \$12.00, and \$10.50 /m_2 for construction alternatives with unstabilized, 6% lime stabilized, and 4% cement stabilized subgrade, respectively. This means that the use of lime stabilization subgrade will reduce the pavement construction cost by 20%, while using cement stabilization subgrade will reduce the cost by 32%. In addition to the above mentioned calculated reduction in pavement construction cost, additional saving in maintenance cost and user cost due to better pavement performance caused by stabilizing the subgrade are expected. Fig 10 shows the layers of thicknesses of pavement sections constructed with the two types of evaluated subgrade stabilized with different types and amounts of stabilizing admixtures.

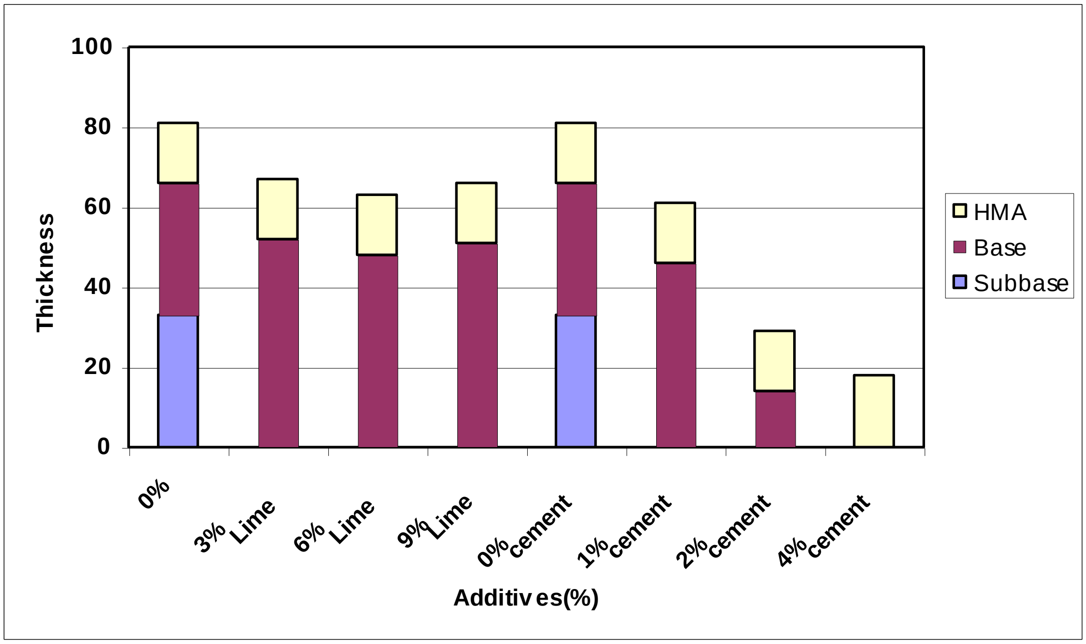
Table 8 Cost of Construction Different Pavement Layers

Pavement Layer	Cost (u.s.\$/m^3)
Hot –Mix Asphalt	60.0
Base	14.0
subbase	10.0
Unstabilized subgrade	2.0
Lime stabilized subgrade	6.2
Cement stabilized subgrade	7.5

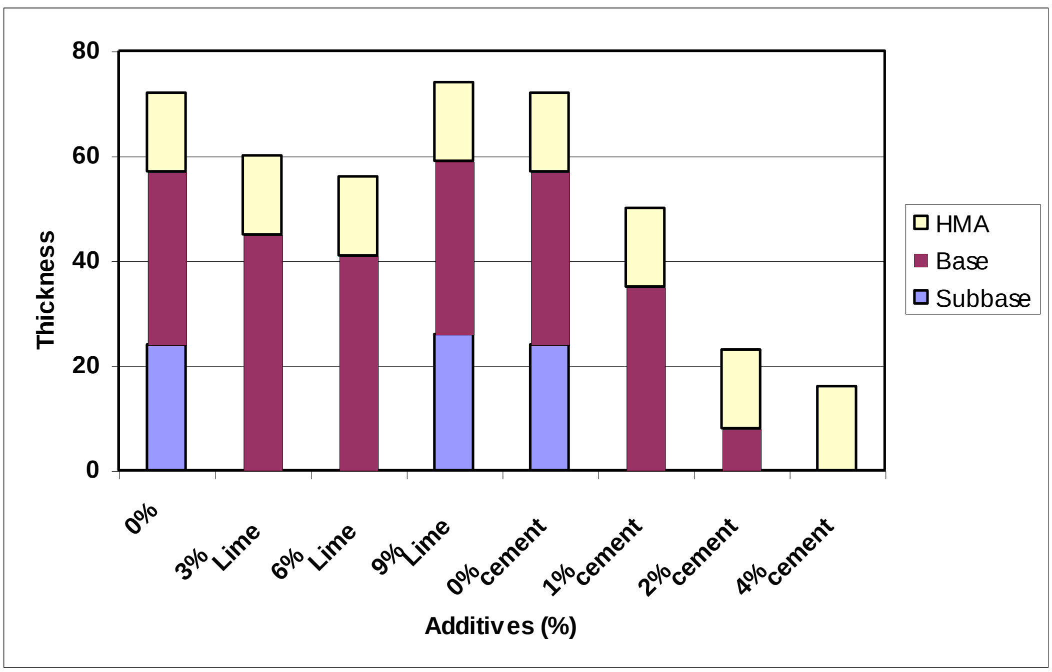
7. Conclusions

Based on the results of the conducted laboratory tests, the following conclusions can be drawn:

1. Stabilizing Irbid subgrade by 6% lime or 4% cement will save in the pavement construction costs by about 20% and 32%, respectively.
2. The effect of cement on improving the CBR value was much more significant than that of lime.
3. Adding a small amount of Portland cement to soil (1% by dry weight) does not significantly affect the soils CBR and unconfined compressive strength values. However, larger amount of these stabilizing admixtures significantly improve the soils CBR and unconfined compressive strength values.
4. For Irbid soil stabilized by lime, the results of the CBR tests showed different trends from that of unconfined compressive strength. The CBR values continued to increase as the amount of admixture increased up to 6% after which the CBR the tended to drop as the amount of lime increased; while the unconfined compressive strength continued to increase with the increase of stabilizing admixtures.
5. The addition of hydrated lime or Portland cement caused a reduction in maximum dry density and a slight increase in optimum moisture content.
6. Six-percent lime by weight of dry soil is the optimum lime content which can be used to improve the strength of the soils under evaluation.
7. The evaluated soils are classified as poor subgrade.



a) Irbid stabilized soils



b) J.U.S.T stabilized soils

Figure 10 Pavement Layers Thicknesses at the Two Types of Evaluated Subgrade Soils Stabilized with Different Types and Amount of Stabilizing Admixtures

8. Recommendations

It is recommended to evaluate the suitability of using other types of stabilizers such as enzyme stabilizers, sulfonated oils and others especially those available as waste materials such fly ash and limestone dust resulting from the manufacturing of building stone. Full scale testing to evaluate the effect of soil stabilization on pavement performance is recommended to be performed. This can be done by constructing a road section on stabilized subgrade and comparing its performance to that with unstabilized subgrade for pavement with similar traffic and environmental conditions. Also, it is recommended to evaluate the effect of weathering (wetting and drying cycles, and freezing and thawing cycles) on the CBR value of stabilized soils.

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