Jordan Journal of Civil Engineering, Volume **6**, No. **1**, **2012**

Effect of Stone Powder and Lime on Strength, Compaction and CBR Properties of Fine Soils

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ABSTRACT

This research is an attempt to investigate the effect of stone powder and lime on the strength, compaction and CBR properties of fine grained soil. The basic properties: direct shear, compaction and CBR were determined first. The stone powder and lime were added at specific percentages (10%, 20% and 30%) by weight of soil and mixed with the optimum moisture content obtained from the compaction test. The direct shear, compaction and CBR tests were conducted directly without curing or soaking of the specimens. The results revealed that the addition of 30% stone powder has increased the angle of internal friction (φ) by about 50% and reduced cohesion by about 64%. The addition of 30% of lime has decreased the friction angle and cohesion by 57% and 28%, respectively. The maximum dry density and optimum moisture content decreased slightly by addition of 30% stone powder, however, the addition of 30% lime decreased the maximum dry density and optimum moisture content by 19% and 13.5%, respectively. The CBR values have increased from 5.2 to 16 and 18 by the addition of 30% stone powder and lime, respectively. The thicknesses of flexible pavement were determined based on the CBR values and assumed daily traffic volume and found to be reduced from 38 cm for soil without additives to 20 cm and 17cm by the addition of 30% of stone powder and lime, respectively.

KEYWORDS: Stone powder, Lime, Strength, Compaction, CBR, Pavement.

INTRODUCTION

In many road construction projects, if weak soils exist, stabilization and improvement of their properties is necessary. The stabilization process aims at increasing the soil strength and reducing its permeability and compressibility. The stabilization processes may include mechanical, chemical, electrical or thermal processes (Ingles and Metcalf, 1972). The process used depends on the type of soil at the site, the time available to execute the project and the stabilization cost compared to the overall cost of the project and to the cost of full replacement of the soil at the site. The engineer may consider one method or several methods together.

In the past few years, utilization of byproduct industrial solid wastes has been the focus of many researches (Tara and Umesh, 2010; Chesner, Collins and Mackay, 1998; Soni and Murty, 1999; Lee and Fishman, 1993; Ciesielski and Collins, 1994; Collins and Emery, 1983; Misra et al., 2010; Misra et al., 2008). Many of the byproduct solid wastes have been recommended to be used as construction materials, especially for road construction.

The production of building stones is one of the important professions in the occupied Palestinian territories. The sources of stones are about 300 stone

Accepted for Publication on 12/9/2011.

quarries situated across the West Bank. All together, there are approximately 700 stone cutting facilities in the West Bank and Gaza. The annual Palestinian production of finished stone and marble is 16 million square meters; equal to 1.6 million tons (USM, 2004). Clearly, the potential of the stone industry is very large. However, many problems and challenges at the national and industry levels remain to be addressed in order to realize potential gains. The major environmental challenge is the disposal of the byproduct stone slurry waste generated during stone cutting and shaping. The total amount of stone slurry waste generated in the Palestinian territories is about 700,000 tons annually. This amount is usually disposed of in open lands and valleys. This action causes many environmental and human threats.

Since the stone slurry waste is proved to consist of more than 95% calcium carbonate, there is a good potential to transfer it to lime in order to be used in soil stabilization. In this study, stone powder and lime are used as stabilizing agents to improve the properties of fine grained soils.

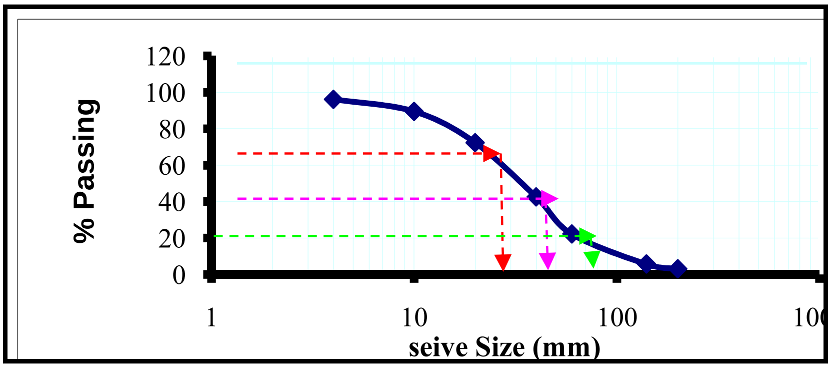

Figure 1: Grain size analysis of the soil

Table 1. Standard proctor test results on soil

γ_{wet} (g/cm³)	γ_{dry} (g/cm³)	Wc (%)	dry-max (g/cm³)	OMC (%)
1.57	1.49	5.4	1.72	17.7
1.69	1.55	9.3		
1.85	1.62	14.2		
2.01	1.71	17.7		
1.91	1.56	22.2		
1.9	1.53	24.5		

Objectives of the Research

The main objective of this research is to utilize stone powder and lime in the improvement of fine soil properties at the routes of medium traffic roads. The two additives are cheap and available in commercial quantities in Palestine. This research will help dispose large quantities of stone slurry and lime by utilizing them in the construction of roads. Therefore, the reduction in the exploitation of raw materials and the mitigation of threats to the environment by stone slurry wastes are of great importance. The variables of this research will include the two additives and three percentages 10%, 20% and 30%.

Methodology

In this research, the experimental method was followed. All variables were kept constant except the experimental variable to check its effect on the results.

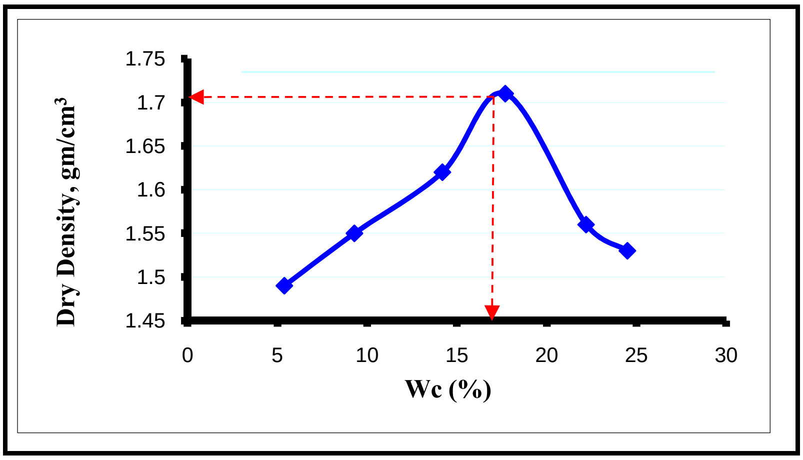

Figure 2: Density-moisture content relationship of the soil

Table 2. Chemical and mineralogical properties of stone powder (Colombo et al., 2005)

Chemicals	Sample 1	Sample 2	Minerals	Sample 1	Sample- 2
	(Max-Min),%	(Max-Min),%		(Max-Min), ppm	(Max-Min), ppm
SiO_2	71.19-33.99	62.55-55.42	Ba	1144.7-392	822-428.6
Al_2O_3	17.09-8.17	15.31-12.21	Rb	239.8-66.9	182-74.3
Fe_2O_3	5.09-1.84	15.12-7.4	Sr	361.9-66.9	465.8-232.4
MgO	11.44-0.7	2.74-1.24	Mo	3.9-0.1	36.3-10.5
CaO	16.77-1.79	7.23-3.37	Cr*	41.1-0.7	417.4-54.7
Na_2O	4.13-1.74	3.8-2.83	Ni*	29.2-1.9	130.6-37.2
K_2O	4.12-1.74	3.68-2.37	Co*	245-54.3	33.3-9.7
TiO_2	0.76-0.21	0.58-0.27	Cu*	163.4-14.4	233.1-67.8
P_2O_5	0.5-0.07	0.23-0.12	As*	1.4-0.5	11.5-2
MnO	0.12-0.04	0.16-0.09	Pb*	91.1-1.4	6.5-1.4
LOI	20.1-0.65	1.55-0.48	Zn*	788-50	72-37
			V*	75-17	68-33
			W	**34.8-0.4**	**13.7-0.9**

The following procedure was followed to achieve the objectives of this research:

1) Preparation and testing of the research soil (fine grained) to identify its physical and mechanical properties.
2) Oven drying and grinding of the stone slurry waste obtained from the sediment ponds of the stone cutting plants.
3) Testing the stone powder and lime to establish their properties.
4) Adding stone powder and lime to the soil and conducting the required tests, such as direct shear, standard proctor and CBR.
5) Using the CBR values determined for the soil with and without additives to determine the thicknesses of flexible pavements from special design figures.
6) Analysis and comparison of the results.

MATERIALS

A. The soil

The soil used in this study was fine grained soil obtained from local road routes in Hebron City. The soil was tested for liquid limit, plastic limit and specific gravity, and the results were found to be 27%, 21.1% and 2.58, respectively. The gradation curve is shown in

Figure (1), the values of D_{10},D_{30}, D_{60},C_c and C_u were found to be 0.125 , 0.295, 0.599, 1.16 and 4.79, respectively. The soil was classified according to the Unified and AASHTO systems and found to be SP and A-3, respectively. The strength properties of the soil was determined from direct shear and found to be C=0.39 kg/cm^2 and φ = 29^o.

The maximum dry density and optimum moisture content were determined from the standard proctor test and found to be 1.72 gm/cm^3 and 17.7%, respectively Figure (2) and Table (1) present the standard compaction test results for soil without additives.

Table 3. Lime chemical and physical properties (Harichane et al., 2010)

Chemical name	Lime
Physical appearance	**Dry white powder**
CaO	> 83.3
MgO	< 0.5
Fe_2O_3	< 2
Al_2O_3	<1.5
SiO_2	<2.5
SO_3	<0.5
Na_2O	0.4 – 0.5
CO_2	<5
$CaCO_3$	<10.0
Specific gravity	2
Over 90 µm (%)	<10
Over 630 µm (%)	0
Insoluble material (%)	<1
Bulk density (g/l)	600-900

Table 4. Results of direct shear tests on soil with additives

Type of additive	(%) of additive	C (kg/cm²)	Φ (degree)
Soil only	0	0.39	29
Stone powder	10	0.08	40.0
	20	0.09	41.5
	30	0.14	45.0
Lime	10	0.19	16.3
	20	0.20	14.3
	30	0.28	12.5

B. The stone powder

It is the byproduct material generated by cutting and shaping of building stones in the stone cutting plants. The water used for cooling up the cutting saw flows out carrying very fine suspended particles as high viscous liquid known as stone slurry. The stone slurry was oven dried, ground and sieved. The values of D_{10},D_{30}, D_{60},C_c and C_u were found to be 0.09 , 0.19, 0.29, 1.37 and 1.53, respectively. Several tests were carried out on stone powder and the results were found to be: liquid limit=23%, non-plastic material specific gravity= 2.59, cohesion (C=0.08 kg/cm^2) and angle of internal friction (φ=35°) (Al-Joulani, 2000). The approximate chemical and mineralogical composition of stone powder is presented in Table (2) as determined in a previous study (Colombo et al., 2005).

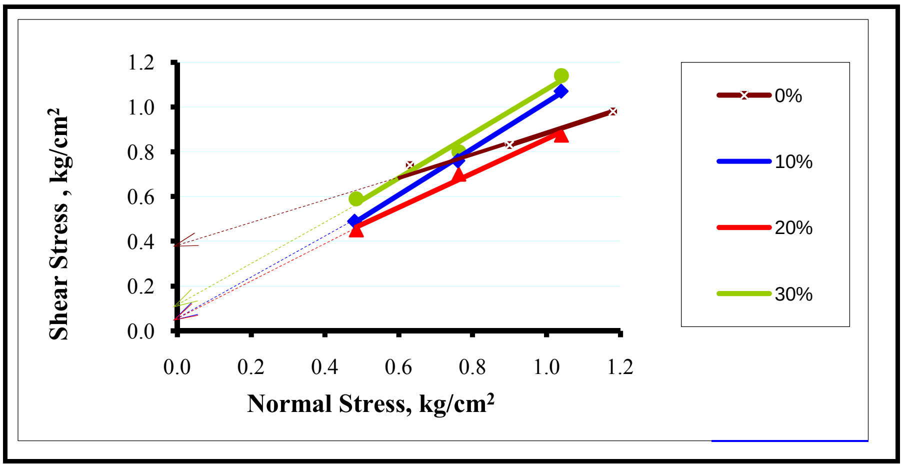

Figure 3: Strength envelope of soils with % of stone powder

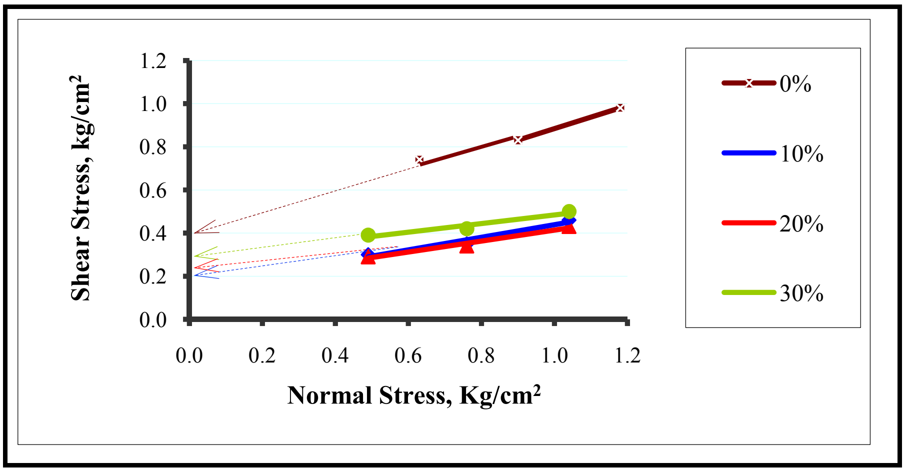

Figure 4: Strength envelope of soils with % of lime

Table 5. Summary of proctor tests on soils with additives

Sample no.	Additive type	% of additive	OMC %	$\gamma_{dry.max}$ (gm/cm^3)
1	Soil only		17.7	1.72
2	Stone powder	10	14.87	1.77
3		20	16.24	1.72
4		30	14.23	1.69
5	Lime	10	20.0	1.45
6		20	25.1	1.4
7		30	15.3	1.39

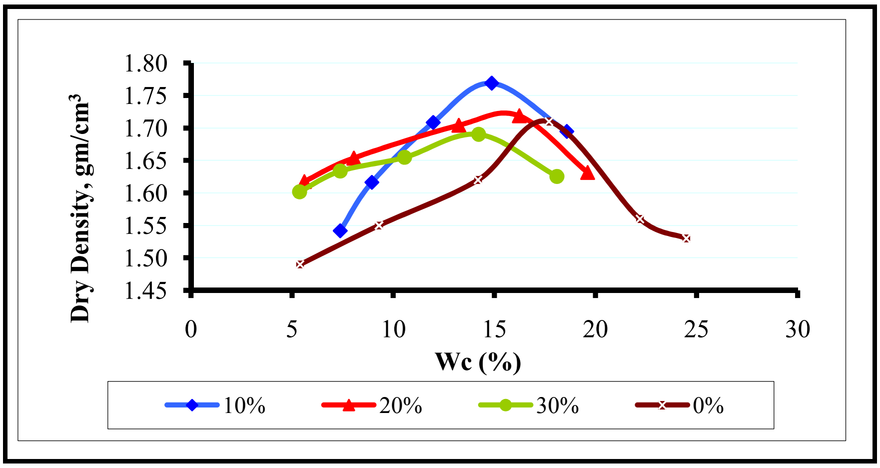

Figure 5: Effect of stone powder (%) on dry density and moisture content

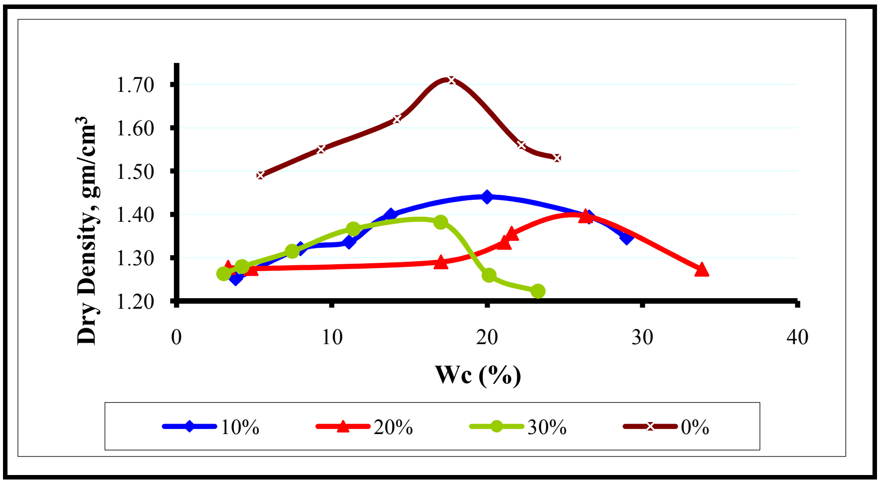

Figure 6: Effect of lime (%) on dry density and moisture content

C. Lime

It is a very fine material used in many construction applications. Lime is produced by burning of calcium carbonate at elevated temperatures and is cooled up to obtain a homogeneous powder. There are many types of lime depending on its chemical composition and contents of calcium and magnesium. There are several studies which addressed the importance of using lime as a construction material and for soil stabilization in particular (Amu et al., 2005; Harichane et al., 2010; Thompson, 2005).

Lime improves the strength of fine soil by three mechanisms: hydration, flocculation and cementation. The first and second mechanisms occur almost immediately upon introducing lime, while the third one has a prolonged effect.

In the present study, hydrated lime was used, $Ca(OH)_2$. It is produced by the reaction of quicklime (CaO) with sufficient water to form a white powder. The sieve analysis results of lime used in this study, for D_{10},D_{30}, D_{60},C_c and C_u were found to be 0.09, 0.15, 0.25, 1.0 and 2.78, respectively. Some results from literature showed that using 7% of lime with fine grained soils will increase the unconfined compressive strength, compaction properties and CBR values. Table (3) presents the chemical composition and some properties of lime (Harichane et al., 2010).

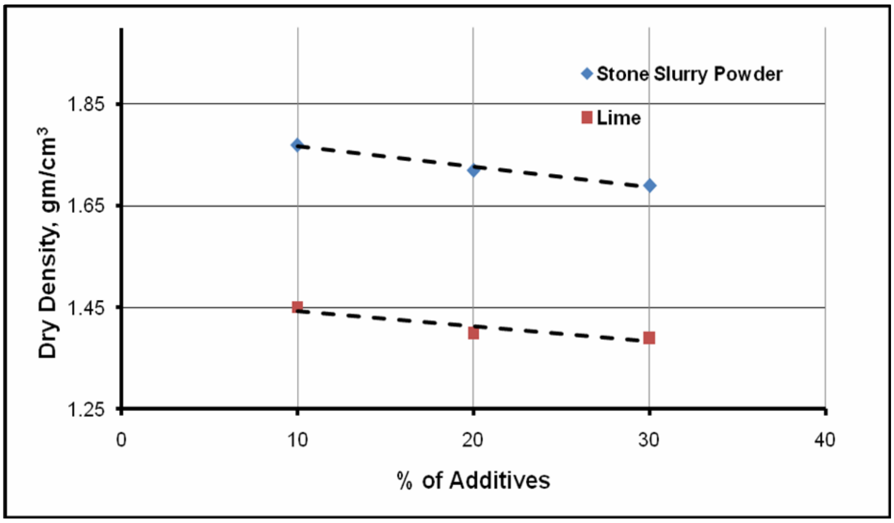

Figure 7: Variation of dry density with % of additives

Table 6. Standard CBR values for crushed stones (Hijawi, 2003)

Penetration (mm)	Standard Load (kg)	Standard Pressure (MPa)	Standard Pressure (kg/cm^2)
2.5	1370	6.9	70
5.0	2055	10.3	105
7.5	2630	13.0	134
10.0	3180	16.0	162
12.7	3600	18.0	183

Table 7. CBR tests results for 3 soil specimens without additives

No. of blows	Weight of mould (kg)	Weight of mould + soil (kg)	Weight of wet sample (kg)	Opt. moist. content (%)	γ_{wet} (g/cm³)	γ_{dry} (g/cm³)
65	7.724	12.114	4.39	0.177	2.2	1.87
30	7.788	12.104	4.316	0.177	2.16	1.83
10	7.746	11.924	4.178	0.177	2.09	1.78

EXPERIMENTAL TESTS RESULTS

A. Direct Shear Test (ASTM D-3080)

Table (4) shows the results of direct shear tests on soil with different percentages of additives. Figures (3 and 4) show the strength envelopes and strength properties (C, φ) of soil with different percentages of additives.

B. Compaction Test (ASTM D-698, AASHTO T-9)

The objective of this test is to determine the maximum dry density ($\gamma_{dry\text{-}max}$) and optimum moisture content (Wc_{opt}) at different percentages of additives and to use these results in the preparation of CBR specimens. Table (5) presents the standard proctor test results and Figures (5 and 6) show the variation of dry density values with moisture contents for soil samples with different percentages of additives. Figure (7) presents the variation of dry density with percentage of additive.

C. CBR Test (ASTM D-1883, AASHTO T-193)

The CBR values are commonly used in mechanistic design and as an indicator of strength and bearing capacity of a subgrade soil, subbase and base course material for use in road and airfield pavements. Two samples are usually prepared for CBR tests; one is tested directly after sample preparation and the other one after soaking in water for 96 hours. The test is carried out under a seating pressure of 4.5 kg and a penetration speed of 1.27 mm/sec. The CBR specimens are prepared by a standard mold with an internal diameter of 152.4 mm (6 inches) and a height of 177.8 mm (7 inches).

In this research, specimens were compacted to a maximum dry density at the optimum moisture content determined by standard proctor tests. The specimens were compacted in 5 layers and tested without soaking in water. The standard CBR values for crushed stones are presented in Table (6). The CBR value is calculated according to the following formula (Hijawi, 2003):

$$CBR = \frac{\text{Measured Pressure}}{\text{Standard Pressure}} \times 100\%$$

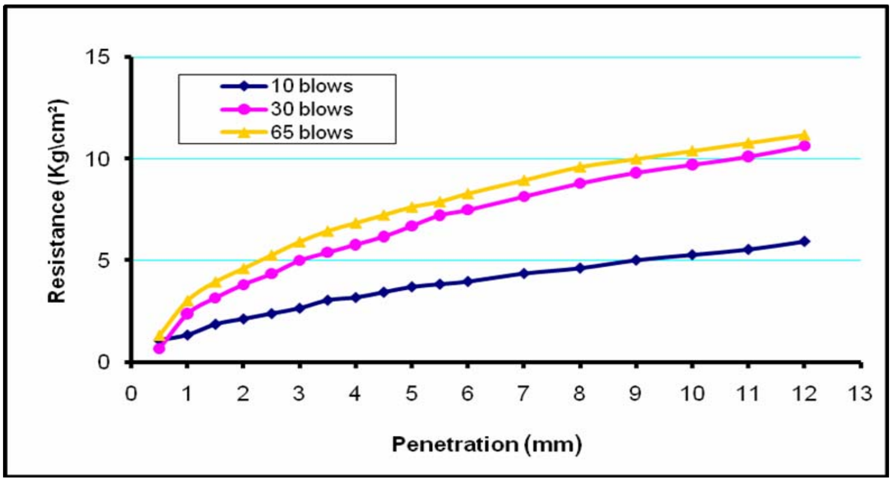

Figure 8: Relationship between resistance and penetration for soil without additives

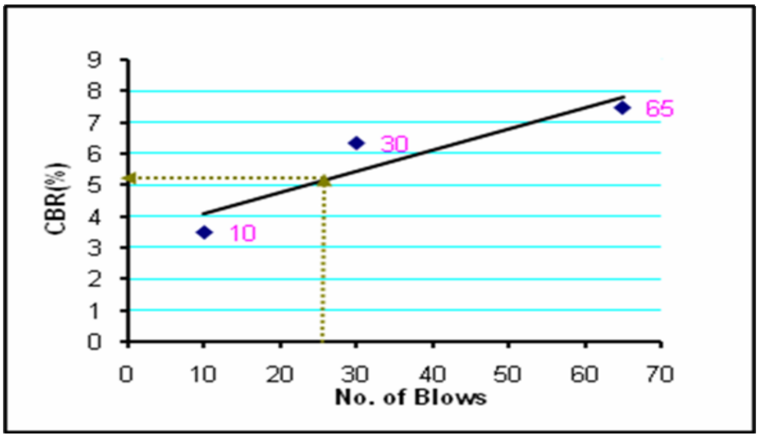

Figure 9: CBR value for soil without additives

Table 8. CBR test results of the three samples of soil with 10% stone powder

No. of blows	Weight of mould (kg)	Weight of mould + soil (kg)	Weight of wet sample (kg)	Opt. moist. content (%)	γ_{wet} (g/cm³)	γ_{dry} (g/cm³)
65	7.724	12.096	4.372	0.1487	2.19	1.90
30	7.788	11.95	4.162	0.1487	2.08	1.81
10	7.746	11.52	3.774	0.1487	1.89	1.64

Table 9. CBR values of the three samples of soil with 10% stone powder

No. of blows	γ_{dry} (g/cm³)	CBR (%)
65	1.9	10.45
30	1.81	10.27
10	1.64	3.86

Table 10. CBR test results of the three samples of soil with 20% stone powder

No. of blows	Weight of mould (kg)	Weight of mould+ soil (kg)	Weight of wet sample (kg)	Opt. moist. content (%)	γ_{wet} (g/cm³)	γ_{dry} (g/cm³)
65	7.724	12.13	4.406	0.1624	2.2	1.90
30	7.788	12.01	4.22	0.1624	2.11	1.82
10	7.746	11.786	4.04	0.1624	2.02	1.74

Table 11. CBR values of the three samples of soil with 20% stone powder

No. of blows	γ_{dry} (g/cm³)	CBR (%)
65	1.9	12.94
30	1.82	12.45
10	1.74	3.86

Table 12. CBR test results of the three samples of soil with 30% stone powder

No. of blows	Weight of mould (kg)	Weight of mould+ soil (kg)	Weight of wet sample (kg)	Opt. Moist. content (%)	γ_{wet} (g/cm³)	γ_{dry} (g/cm³)
65	7.724	11.984	4.26	0.1423	2.13	1.87
30	7.788	11.722	3.934	0.1423	1.97	1.72
10	7.746	11.312	3.566	0.1423	1.78	1.56

a) CBR of Soil without Additives

In this research, three samples were prepared for CBR tests at the same moisture content. Each sample was compacted with a different number of blows (10, 30 and 65). The CBR tests were conducted directly (without soaking in water). Table (7) presents the CBR test results of the 3 samples of soil without additives. The relationships between resistance and penetration are plotted in Figure (8). The CBR values were determined at 2.5 mm and 5 mm penetration. If the value of CBR at 5 mm was larger, the test was repeated, and if it was still larger, it was selected as the CBR value. The relationship between CBR and the number of blows is plotted in Figure (9). The CBR value which corresponds to 25 blows is determined to be 5.2.

b) CBR of Soil +10% Stone Powder

Table (8) presents the results of CBR tests for soil with 10% stone powder for three samples at different compaction efforts (10, 30 and 65 blows) and Table (9) presents the CBR values. By plotting the results in a similar manner as in Figures (8 and 9) for soil without additives, the value of CBR can be determined at 25 blows to be 7.

c) CBR of Soil +20% Stone Powder

Table (10) presents the results of CBR tests for soil with 20% stone powder for three samples at different compaction efforts (10, 30 and 65 blows) and Table (11) presents the CBR values. By plotting the results in a similar manner as in soil without additives and as in soil with 10% stone powder, the value of CBR is determined at 25 blows to be 8.2.

Table 13. CBR values of the three samples of soil with 30% stone powder

No. of blows	γ_{dry} (g/cm³)	CBR (%)
65	1.87	32.49
30	1.72	22.4
10	1.56	7.47

Table 14. CBR test results of the three samples with 10% lime

No. of blows	Weight of mould (kg)	Weight of mould+ soil (kg)	Weight of wet sample (kg)	Opt. moist. content (%)	γ_{wet} (g/cm³)	γ_{dry} (g/cm³)
65	7.724	11.964	4.24	0.20	2.12	1.77
30	7.788	11.758	3.97	0.20	1.99	1.66
10	7.746	11.53	3.784	0.20	1.89	1.58

Table 15. CBR values of the three samples of soil with 10% lime

No. of blows	γ_{dry} (g/cm³)	CBR (%)
65	1.77	8.09
30	1.66	7.59
10	1.58	6.84

d) CBR of Soil +30% Stone Powder

Table (12) presents the results of CBR tests for soil with 30% stone powder for three samples at different compaction efforts (10, 30 and 65 blows) and Table (13) presents the CBR values. By plotting the results in a similar manner as with 10% and 20% stone powder, the CBR value is determined at 25 blows to be 16.

e) CBR of Soil +10% Lime

Table (14) presents the results of CBR tests for soil with 10% lime for three samples at different compaction efforts (10, 30 and 65 blows) and Table (15) presents the CBR values for the three samples. By plotting the results as discussed earlier, the CBR value is determined at 25 blows to be 7.4.

Table 16. CBR test results of the three samples with 20% lime

No. of blows	Weight of mould (kg)	Weight of mould+ soil (kg)	Weight of wet sample (kg)	Opt. moist. content (%)	γ_{wet} (g/cm³)	γ_{dry} (g/cm³)
65	7.724	11.78	4.056	0.251	2.03	1.62
30	7.788	11.604	3.816	0.251	1.91	1.53
10	7.746	11.46	3.714	0.251	1.86	1.49

Table 17. CBR values of the three samples of soil with 20% lime

No. of blows	γ_{dry} (g/cm³)	CBR (%)
65	1.62	21.65
30	1.53	19.79
10	1.49	8.02

Table 18. CBR test results of the three samples with 30% lime

No. of blows	Weight of mould (kg)	Weight of mould+ soil (kg)	Weight of wet sample (kg)	Opt. moist. content (%)	γ_{wet} (g/cm³)	γ_{dry} (g/cm³)
65	7.724	11.346	3.622	0.153	1.81	1.57
30	7.788	11.114	3.326	0.153	1.66	1.44
10	7.746	10.82	3.074	0.153	1.54	1.33

Table 19. CBR values of the three samples of soil with 30% lime

No. of blows	CBR (%)	γ_{dry} (g/cm³)
65	46.69	1.57
30	23.64	1.44
10	7.47	1.33

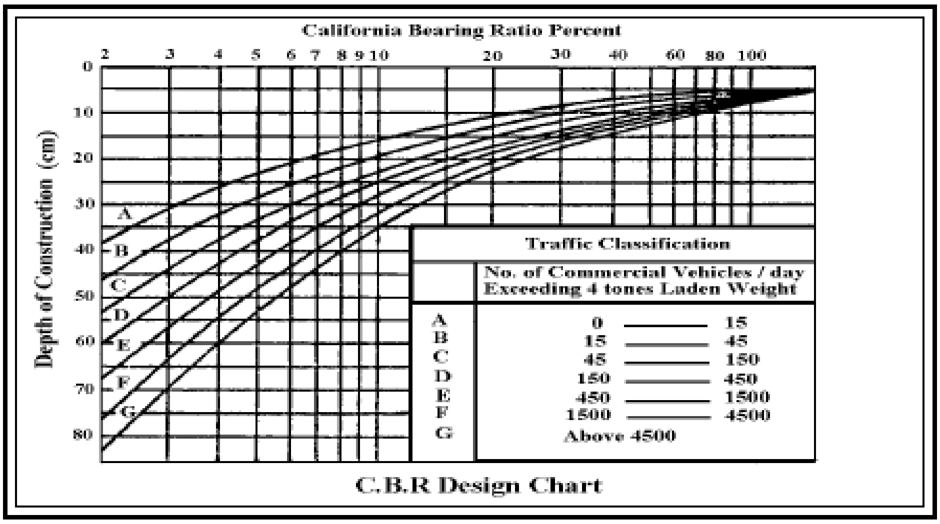

Figure 10: Design charts for flexible pavement using CBR values (Hijawi, 2003)

Table 20. Summary of CBR values at different numbers of blows for soil with stone powder at all percentages

No. of blows	Avg. γ_{dry} (g/cm³)	CBR (%) Soil only	CBR (%) Soil +10% Stone slurry	CBR (%) Soil +20% Stone slurry	CBR (%) Soil +30% Stone slurry
65	1.89	7.47	10.45	12.94	32.49
30	1.80	6.34	10.27	12.45	22.4
10	1.68	3.49	3.86	3.86	7.47

Table 21. Summary of CBR values at different numbers of blows for soil with lime at all percentages

No. of blows	Avg. γ_{dry} (g/cm³)	CBR (%) Soil only	CBR (%) Soil +10% Lime	CBR (%) Soil +20% Lime	CBR (%) Soil +30% Lime
65	1.71	7.47	8.09	21.65	46.69
30	1.62	6.34	7.59	19.79	23.64
10	1.55	3.49	6.84	8.02	7.47

Figure 22. Summary of CBR values at 25 blows and the corresponding pavement thicknesses with all % of additives

Type of Soil	Additive (%)	γ_{max} gm/cm³	OMC (%)	CBR (%)	Thickness of Pavement (cm)
Soil Only		1.72	17.7	5.2	38
Soil + Stone Slurry	10%	1.77	14.87	7	32
	20%	1.72	16.24	8.2	28
	30%	1.69	14.23	16	20
Stone + Lime	10%	1.45	20.0	7.4	21
	20%	1.40	25.1	15	19
	30%	1.39	15.3	18	17

Table 23. Comparison of soil properties in this study and in a similar study (Misra et al., 2010) on coarse grained soils

Study	Soil Type	OMC (%)	$\gamma_{dry\text{-}max}$ (g/cm³)	CBR (%)	φ (Deg.)	C kg/cm²	P_I (%)	Pl (%)	LL (%)
Current study	Fine grained (SP)	17.7	1.72	5.2	29	0.39	5.9	21.1	27
Misra et al. (2010)	Coarse grained (SM)	11.0	1.9	12.5	40	0.03	6.5	22.5	29

f) CBR of Soil +20% lime

Table (16) presents the results of CBR tests for soil with 20% lime for three samples at different compaction efforts (10, 30 and 65 blows) and Table (17) presents the CBR values for the three samples. By plotting the results as discussed earlier, the CBR value is determined at 25 blows to be 15.

g) CBR of Soil +30% lime

Table (18) presents the results of CBR tests for soil with 10% lime for three samples at different compaction efforts (10, 30 and 65 blows) and Table (19) presents the CBR values for the three samples. By plotting the results as discussed earlier, the CBR value is determined at 25 blows to be 18.

Table 24. Comparison of results for fine soil (current study) and similar study (Misra et al., 2010), for coarse grained soils at the same % of stone powder

		Current Study			Misra et al. (2010)		
	Additive (%)	CBR (%)	OMC (%)	γ_{max} gm/cm^3	CBR (%)	OMC (%)	γ_{max} gm/cm^3
Soil Only	0.0	5.2	17.7	1.72	12.5	11.0	1.9
Soil + Stone Slurry Powder	10	7	14.87	1.77	16.5	11.6	1.95
	20	8.2	16.24	1.72	17.7	11.9	1.93
	30	16	14.23	1.69	10.2	12.1	1.914

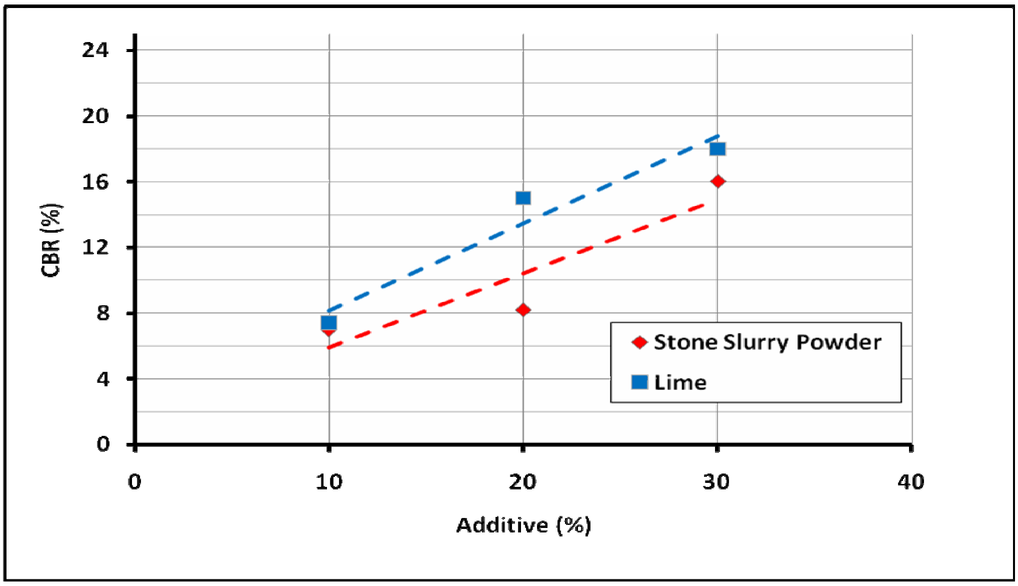

Figure 11: Variation of CBR values with % of additives

Analysis and Discussion

A pavement is designed to support wheel loads. Topmost layer is surfaced to provide a smooth, tough, dust free, reasonably water proof and strong layer. Base which comes immediately next below is medium, through which stresses imposed are evenly distributed. Additional help in distributing loads is provided by sub-base layer. Sub-grade is compacted natural earth immediately below pavement layers. Top of sub-grade is also known as formation level (Misra et al., 2010).

To find the thickness of flexible pavement in this research, the CBR values were determined at 25 blows as shown in Figure (9) for soil with and without additives. By using the values of CBR in Figure (10), curve D, the thickness of flexible pavement can be figured out. Table (20) presents a summary of the results of CBR tests at different numbers of blows for fine soils with stone powder and Table (21) presents similar results for fine soils with lime at all percentages.

Table (22) presents a summary of all CBR values at 25 blows and the corresponding pavement thicknesses as determined from Figure (10). It can be observed from the Table, that the CBR value increases from 5.2% for soil without additives to 16% and 18% by addition of 30% stone powder and lime. According to Bowles (1992), the sub-grades having 0-7% CBR values are very poor and poor to fair, and those of 7-20% are fair. Therefore, it can be stated from the CBR results in this study, that stone powder and lime treatments have converted the quality of fine grained soil from poor to fair/good sub-grade material.

The thickness of flexible pavement is reduced by 47% and 55% by using 30% of stone powder and lime, respectively. These results agree well with some results documented in the literature (Amu et al., 2005), which reported an increase of 45.5% in CBR values when using 7% of lime. Figure (11) shows the variation of CBR with % of additives and Figure (12) presents the variation of pavement thickness with % of additives.

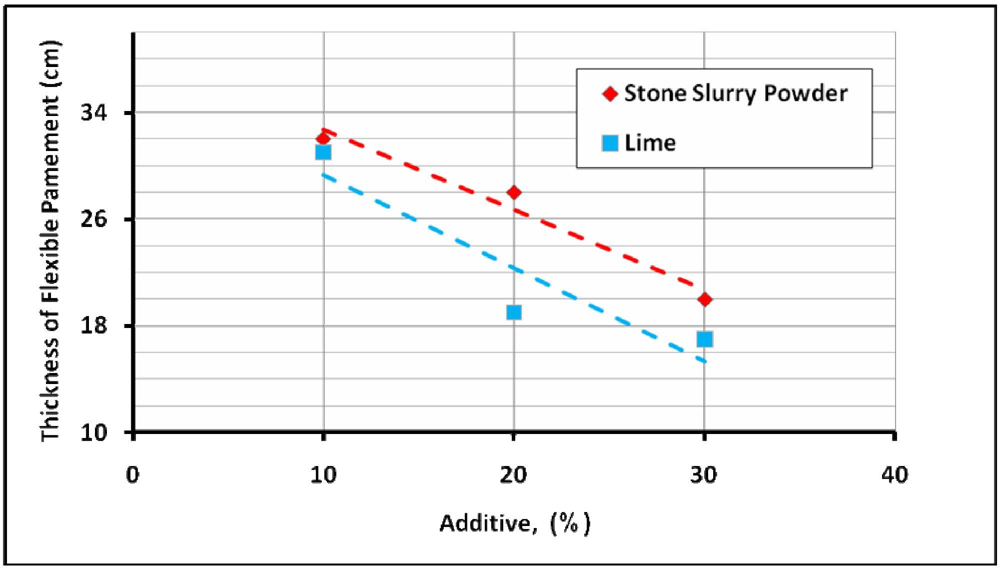

Figure 12: Variation of flexible pavement thickness and % of additives

A comparison of test results was carried out for fine grained soil (SP) with stone powder from this study and those in a similar study conducted on coarse grained soil (SW) with stone powder at the same percentages (Misra et al., 2008). Table (23) shows a comparison between soil properties and Table (24) presents a comparison of the compaction and CBR test results from both studies. Comparing the CBR values in Table (24), it can be noticed that the optimum percentage of stone powder was at 30% and 20% for fine and coarse grained soils, respectively.

CONCLUSIONS

In this research, several tests were carried out using stone powder and lime as additives for fine grained soil. The main objective of the research was to improve the strength and bearing capacity of fine grained soils at local road routes, where this kind of soil exists. The main tests carried out were direct shear, standard compaction and the California Bearing Ratio (CBR) tests. The two additives were mixed with the soil at percentages of 10%, 20% and 30% by weight. The following conclusions can be withdrawn:

1) Using 30% of stone powder has increased the angle of internal friction (φ) by about 50% and reduced the cohesion by about 64%. The addition of 30% of lime has decreased the friction angle and cohesion by 57% and 28%, respectively.
2) Using 30% of stone powder reduced the maximum dry density and optimum moisture content slightly. However, the addition of 30% lime decreased the

maximum dry density and optimum moisture content by 19% and 13.5%, respectively.

3) The addition of 30% stone powder and lime has increased the CBR value from 5.2% to 16% and 18%, respectively. The increase in CBR values due to stone powder and lime caused a reduction in the flexible pavement thickness by 47% and 55%, respectively. This means substantial saving in the material needed for construction of roads.
4) The results from this study agree well with some recent studies from literature related to the potential utilization of substantial amounts of stone powder in road construction.

Recommendation

The soil used in this study has specific properties, and the CBR tests were conducted on un-soaked samples and without consideration of the time effect after mixing additives with the soil. More studies are needed to test soaked samples, considering the effect of curing time after mixing stone powder and lime with soil.

REFERENCES

Al-Joulani, Nabil. 2000. Engineering Properties of Slurry Waste from Stone Cutting Industry in the West Bank, First Palestine Environmental Symposium, PPU, Hebron.

Amu, O.O., Fajobi, A.B. and Oke, B.O. 2005. Effect of Eggshell Powder on the Stabilizing Potential of Lime on and Expansive Clay Soil, *Research Journal of Agriculture and Biological Sciences*, 1 (1): 80-84.

Bowles, J. 1992. Engineering Properties of Soil and their Measurements, McGraw-Hill

Chesner, W.H., Collins, R.J. and Mackay, M.H. 1998. User Guidelines for Waste and By-Product Materials in Pavement Construction, Report No. FHWA-RD-97-148, Federal Highway Administration, US Department of Transportation, Washington, DC.

Ciesielski, S.K. and Collins, R.J. 1994. Recycling and Use of Waste Materials and By-Products in Highway Construction, National Cooperative Highway Research Program Synthesis of Highway Practice 199, Transportation Research Board, Washington, DC.

Collins, R.J. and Emery, J.J. 1983. Kiln Dust-Fly Ash Systems for Highway Bases and Subbases, Report No. FHWA/RD-82/167, Federal Highway Administration.

Colombo, Annita, Tunesi, Annalisa, Barberini, Valentina, Galimberti, Lucia and Cavallo, Alessandro. 2005. Chemical and Mineralogical Characterization of Cutting Sludge Process, Exploration of Sludge from Stone Working, Synthesis of the Research, from www.aigt.ch

Harichane, K., Ghrici, M., Khebizi, W. and Missoum, H. 2010. Effect of the Combination of Lime and Natural Pozzolana on the Durability of Clayey Soils, *EJGE*, 15, Bund. L.

Hijawi, Sami A. 2003. Soil Tests for Construction Purposes, PECDAR, Edition No.1, Palestine.

Ingles, O.G. and Metcalf, J.B. 1972. Soil Stabilization, Principles and Practice. Chapters 1-11, Butterworths, Melbourne.

Lee, S.W. and Fishman, K.L. 1993. Waste Products as Highway Materials in Flexible Pavement Systems, *Journal of Transportation Engineering*, 119 (3): 433-449.

Misra, A., Gupta, R. and Gupta, R.C. 2008. Utilization of Marble Slurry in Construction Materials, Workshop on Gainful Utilization of Marble Slurry and Other Stone Wastes, Indian School of Mines, accessed, http: //www.cdosindia.com/papers//marble_slurry_workshop /anurag_mishra-utilisation_of marble_slurry in_ construction.doc

Misra, A., Mathur, R., Rao, Y., Singh, A. and Pankaj, Goel. 2010. A New Technology of Marble Slurry Waste Utilization in Roads, *Journal of Scientific and Industrial Research*, 69: 67-72.

Soni, S.K. and Murty, A.V.S.R. 1999. Utilization of

Industrial Wastes in Low-Volume Roads, Transportation Research Record, Seventh International Conference on Low-Volume Roads, 1652, 1:246-256.

Tara Sen and Umesh Mishra, 2010. Usage of Industrial Waste Products in Village Road Construction, *International Journal of Environmental Science and Development*, 1 (2), June 2010. ISSN:2010-0264.

Thompson, R. Marshall. 2005. Admixture Stabilization-Lime Treatment of Subgrades, Technical Note No. 14, Center of Excellence for Airport Technology, University of Illinois, USA.

Union of Stone and Marble Industry (USM). 2004. First Edition, Hebron, West Bank, Palestine.