OPTIMIZATION OF CEMENT-LIME-CHEMICAL ADDITIVES TO STABILIZE JORDANIAN SOILS

NAGIH M. EL-RAWI*
MOHAMMAD M.Y. AL-SAMADI**

SUMMARY: The prospects of stabilizing typical Jordanian soils from three regions were investigated. Cement, lime, and alkali sodium chemical additives were used to find the optimum combination that produce the best unconfined compressive strength and C.B.R. results. It was found that clayey silt from Zeizia region requires 9% cement by weight of dry soil or 7% cement + 2% lime to be stabilized. The amount of stabilizing agent could be reduced if sodium hydroxide or carbonate of 0.5 N is added to the mixture. The silty clay from Irbid area requires 12% cement or 8% cement + 4% lime to meet the soil cement strength criterion. The sodium alkalis could reduce the total cementing agent. The marly clay from Na'ur area was found to show poor response to cement. It requires 18% sulphate resisting cement. It shows negative response to the alkali sodium chemicals used.

Concerning the amount of stabilizer for each soil, the choice depends on the availability, the cost, and the economical conditions of the concerned area and time of construction.

Key Words: Cement, lime, alkali sodium, unconfined compressive strength, C.B.R.

INTRODUCTION

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 (1,2).

Soils could be stabilized by mechanical, chemical, electrical, or thermal means (3,4). Chemical stabilization includes the addition of cement, lime, asphalt, chemical compounds, or a combination of those (5-7).

The first controlled soil-cement construction was a road built in 1935 near Johnsoville, South Carolina, U.S.A. (8-11).

Since then soil-cement has been increasingly used as a satisfactory base, sub-base, and to improve the subgrades for modern highway and arfield pavements (12,13).

Lime as a soil stabilizer is among the oldest techniques for road construction, dating back to the Romans (14,15). Lime reduce the plasticity of highly plastic soils and hence make them more workable (16-18). 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.

Sodium hydroxide and carbonate were found to be effective chemical additives with Iraqi soils stabilized by cement or lime (19,20).

The objective of this work was to investigate the best combination of cement, lime, and alkali sodium chemicals to stabilize three Jordanian soils for the purpose of highway and airfield pavement construction.

MATERIALS AND METHODS

Soils: Three typical Jordanian soils selected for this study were; a light brown clayey silt from Zeizia region, a dark brown silty clay from Irbid region, and a greenish marly clay from Na'ur region. The location of the samples and the main soil types in Jordan are shown in Figure 1. The physical and chemical properties of the soils are given in Tables 1 and 2 respectively. Figures 2 and 3 show the grain size distribution and the mineral composition of the soils respectively. The standard Proctor compaction curves for the three soils are shown in Figure 4.

*College of Eng., University of Baghdad, Baghdad, Iraq.
**Civil Engineering Ministry of Public Works and Housing, Amman, Jordan.

Table 1: Physical properties of soils.

Soil Location	Irbid	Na'ur	Zeizia
Specific Gravity (AASHTO T 100 - 86) (48)	2.70	2.75	2.72
Atterberg Limits:			
- Liquid limit (%) (AASHTO T 89 - 86) (48)	52	51	34
- Plastic limit (%) (AASHTO T 90 - 86) (48)	29	24	22
- Plasticity Index (%) (AASHTO T 90 - 86) (48)	23	27	12
Grain Size Distribution (ASTM D422 - 63) (49)..			
- Sand (> 0.074 mm) (%)	11	3	4
- Silt (< 0.074 and> 0.005 mm) (%)	34	28	51
- Clay (<0.005 mm) (%)	55	69	45
Standard Proctor Compaction (AASHTO T 99 - 86) (48)			
- Maximum Dry Density (kg/m^3)	1546	1674	1656
- Optimum Moisture Content (%)	22.7	20.5	20.4
California Bearing Ratio (%) (AASHTO T 193 - 81) (48)	3.8	2.5	9.8
Swell (%)	4.93	2.7	0.8
AASHTO Soil Classification (M1 45 - 82) (48)	A-7-6 (24)	A-7-6 (29)	A-6 (13)
Unified Soil Classification (ASTM D2487 - 83) (49)	CH	CH	CL
Soil Description ASTM (D2488 - 69) (49)	Dark brown silty clay	Greenish marly silty clay	Light brown silty clay

Lime: Unhydrated (quick) lime produced in Iraq was used in this investigation.

Cement: Ordinary Portland cement (type I) and sulphate resisting cement (type V). Produced by the Jordan cement Factories Co. Ltd. were used. The chemical composition of the cement and lime are given in Table 3.

Chemical Additives: The chemical additives of sodium hydroxide (NaOH) and Sodium Carbonate (Na_2CO_3) used were water soluble laboratory reagents with concentrations varied from 0.25 N to 2.0 N.

Water: Potable water was used throughout the study, except where standard specifications require distilled water.

Equipments, Specimens and Tests

Unconfined Compression Test: The air dried pulverized soils were mixed with the required amount of the stabilizer, the required amount of water was added, specimens having a diameter of 5.08 cm (2.0 inch.) and a height of 10.16 cm (4 inch.) were prepared by impact compaction. Model hammer and mold to produce equivalent compaction energy to standard

Table 2: Chemical properties of soils.*

Soil Location		Irbid	Na'ur	Zeizia
Chemical Analysis*:	Na_2O (%)	0.00	0.01	0.00
(X - Ray Flourescence)	MgO (%)	2.13	2.73	2.21
	Al_2O_3 (%)	15.06	11.90	11.00
	SiO_2 (%)	61.65	52.08	61.52
	P_2O_5(%)	0.09	0.08	0.15
	K_2O(%)	1.86	1.38	1.71
	CaO(%)	4.12	12.23	10.37
	TiO_2(%)	1.14	1.04	0.96
	MnO(%)	0.00	0.00	0.00
	Fe_2O_3(%)	9.06	7.33	6.35
	**SO_3(%)	0.00	2.02	0.00
Organic matter content**	(%)	4.0	4.1	4.5
PH**		7.22	7.20	7.15

*Tests were conducted by the Natural Resources Authority/Jordan

** Tests were conducted by the Ministry of Public Works Laboratories/Jordan

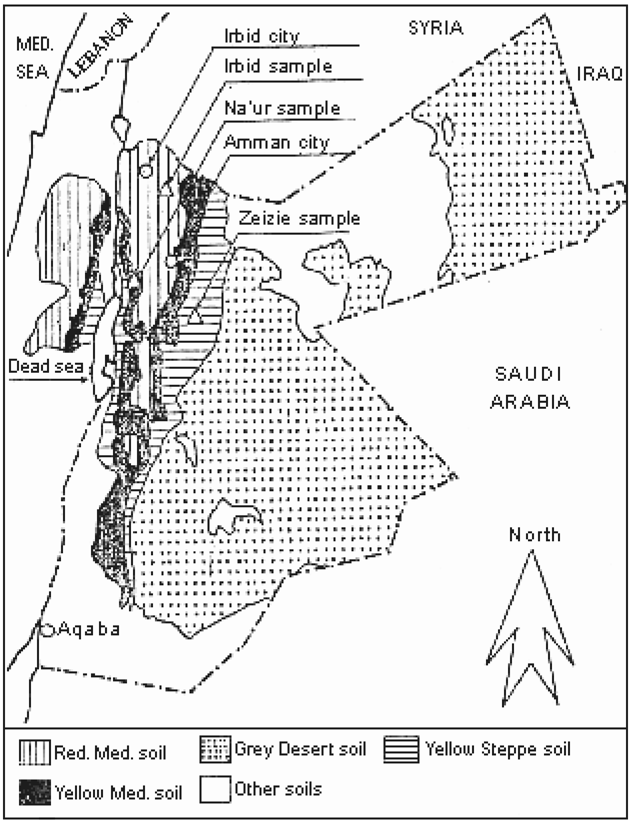


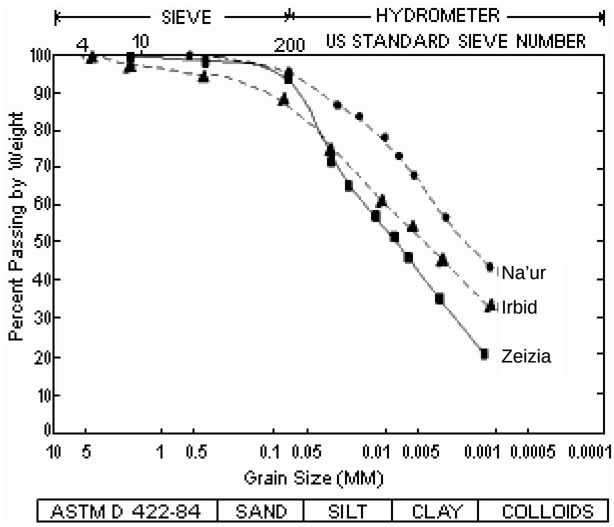
Figure 1: Distribution of main soil types in Jordan (After Masannat (21)).

Table 3: The chemical composition of cement and lime.

Oxide	Percent by weight: Ord. Portland Cement-type I*	Sulphate resisting Cement-type V*	lime **
SiO_2	21.70	21.90	1.05
Al_2O_3	6.10	4.10	0.42
Fe_2O_3	3.60	4.50	0.18
CaO	58.80	65.50	54.40
MgO	3.60	2.10	0.98
SO_3	3.00	1.00	2.10
K_2O	0.72	0.54	0.11
NaO	0.44	-	0.98
Loss of Ignition	1.50	-	40.20
Tricalcium Aluminate	9.06	3.30	

*Tests were conducted by the Jordan Cement Factories Co. Ltd.
** Tests were conducted by the Natural Resources Authority - Jordan.

Figure 2: Grain size distribution of three soils.



proctor compaction was utilized. The prepared and cured specimens were tested for the unconfined compression test in accordance with ASTM-D-1633. The specimens were loaded at a constant strain rate of 1.3 mm/min (0.05 inch/min). The unconfined compressive strength q_u values reported are the average of the three tests.

Figure 3: X-Ray diffraction for soils used.

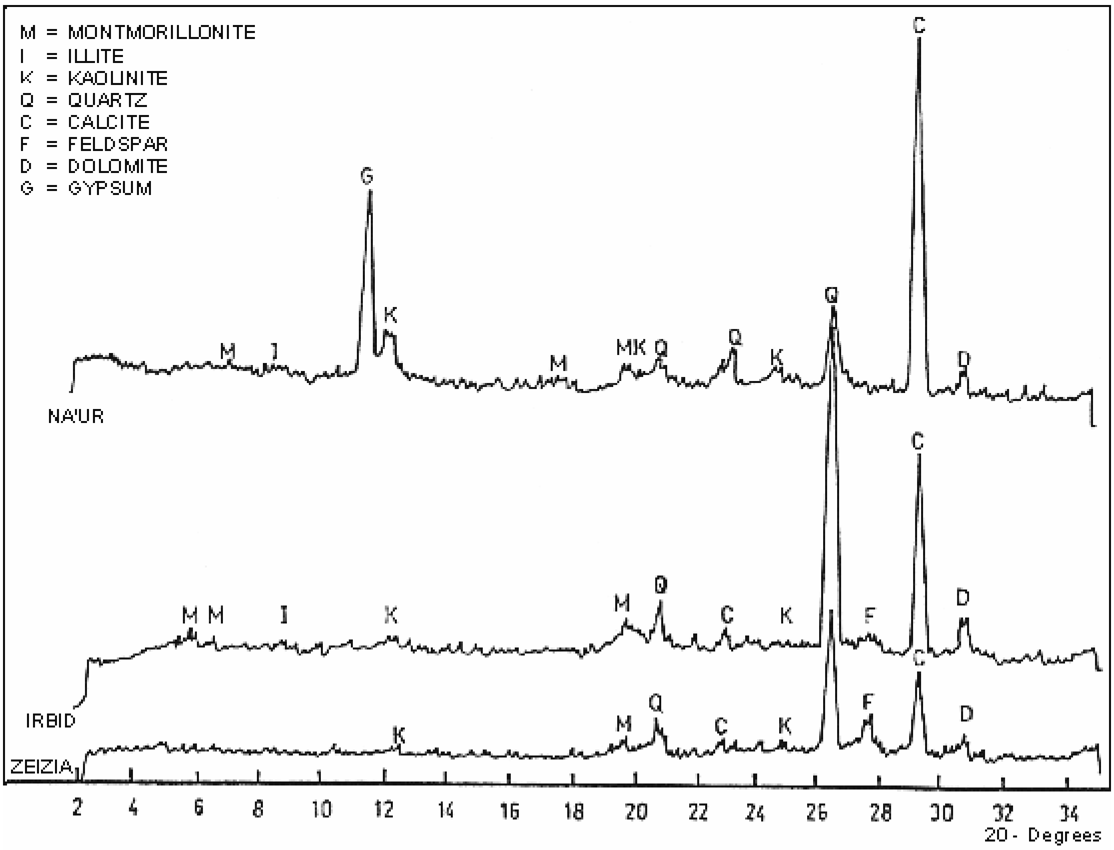
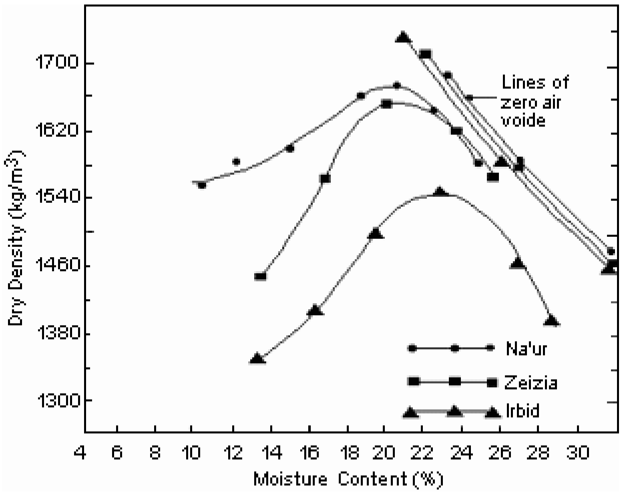


Figure 4: Moisture - Density relationship for all soils (standard Proctor T99-86).



California bearing ratio (C.B.R.):

C.B.R. specimens were prepared by a standard C.B.R. mold of internal diameter of 152.4 mm. (6 inch.) and a height of 177.8 mm (7 inch). Specimens were compacted to the maximum dry density at the optimum moisture content determined by standard proctor. The specimens were compacted in 5 layers. When cured, the specimens were soaked in water for 4 days under the surcharge weight. The C.B.R. tests were carried out in accordance with AASHTO-T-193-81.

RESULTS

When the stabilized soil was compacted at optimum moisture content at a compactive effort equivalent to the standard proctor compaction the following results were obtained:

1. The effect of lime content on the unconfined compressive strength at 7 days curing age for the three soils is shown in Figure 5. The three soils are regarded as lime reactive soils according to Thompson's classification (22). There is an optimum lime content of about 6% by weight that produce maximum strength; increasing the lime content beyond this is not beneficial. The maximum q_u for the soil from Irbid stabilized with lime was found to be 1200 KN/m^2. While the soils from Zeizia and Na'ur gave unconfined compressive strengths (q_u) of 600 and 400 KN/m^2 when stabilized with lime at the age of 7 days. The silty clay from Irbid reacted better than the clayey silt from Zeizia when treated with lime.

2. When the three soils were stabilized with cement the clayey silt from Zeizia gave better response to stabilization with cement. The following results were obtained:

a) The unconfined compressive strength increases linearly with the increase in cement content as shown in Figure 6.

The soil from Na'ur region gave lower results and requires higher % of sulphate resisting cement for effective stabilization.

Figure 5: Effect of lime content on the unconfined compressive strength of the three soils used,compacted to maximum dry density at O.M.C. and cured for 7 days at temperature of 25°C.

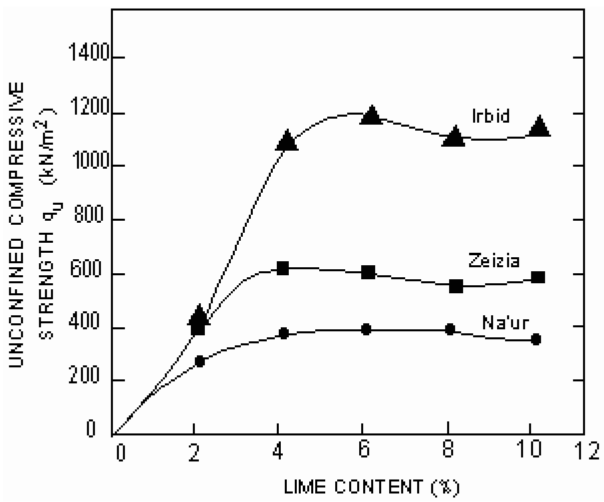
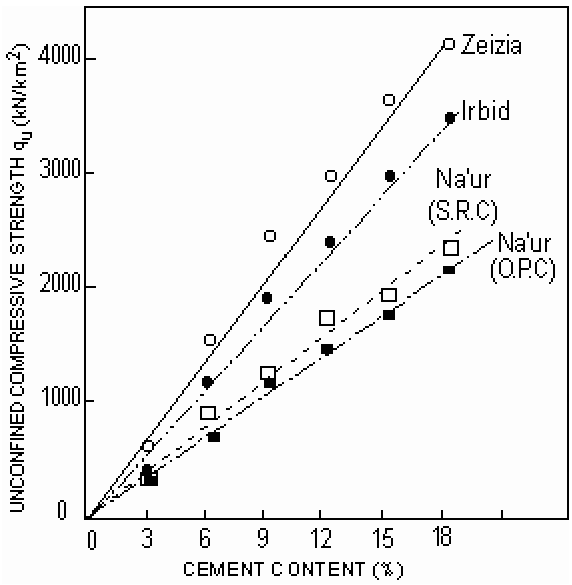
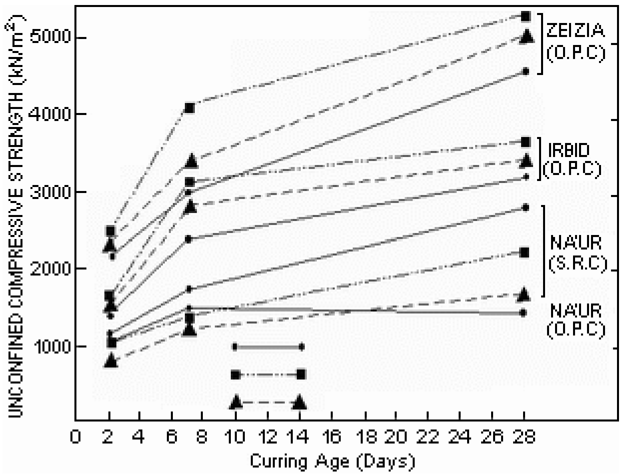


Figure 6: Effect of cement content on the unconfined compressive strength of soils used, cured for 7 days.



b) Figure 6 indicates that 9% cement content by weight will be required to stabilize the soil from Zeizia while 12% cement will be required for the soil from Irbid, if 7 days compressive strength of 2100 KN/m^2 (300 PSI) is taken as a criteria. The soil from Na'ur reqiures 18% sulphate resistance cement since ordinary portland cement does not work because of the high sulphate content in the raw soil, (SO_3 = 2.02%), as shown in Figure 7 which illustrate the gain in strength with curing age.

Figure 7: Effect of curing age on the unconfined compressive strength of three soils, stabilized with 12% cement and chemical additives.



c) The effect of using chemical additives with the three soils stabilized by 12% cement content is shown in Figure 7. While the use of NaOH and Na_2CO_3 with 0.5 normality was beneficial in case of the two soils from Zeizia and Irbid, it did not work with the greenish marly clay refered to as yellow Mediterranean soil from Na'ur.

d)The addition of NaOH produce higher strength than Na_2CO_3 for the three soils when specimens were cured up to 28 days. This is because NaOH would immediately raise the PH of the solution, dissolve more silica and alumina from the soil which results in the formation of extra gel. While the Carbonate is not sufficiently basic to attack the soil silica directly.

Moh (23) reported that the efficiency of sodium compounds on soilcement mixtures, decrease with the increase in the plasticity and organic matter of the soil or both.

e) The effect of the concentration of the chemical additive on the strength of the stabilized soils is shown in

Figure 8: Effect of type and concentration of additives on the unconfined compressive strength of soils, stabilized with 12% cement, cured for 7 days.

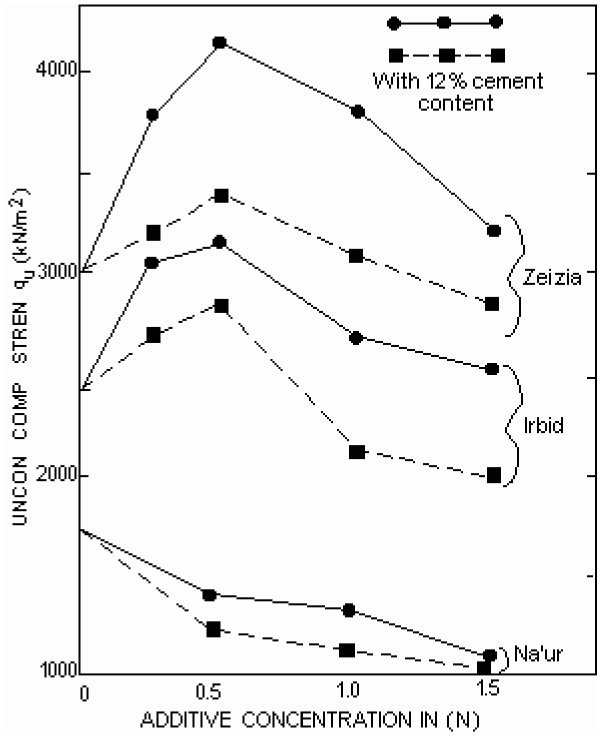


Figure 8. When the additive is beneficial, 0.5 N produce the optimum strength.

3. The effect of lime on soil-cement mixtures could be thought of either to replace some of the cement, hence to reduce the cement content required or as an additive to soil-cement. The following results were observed:

a) When lime is used to replace some of the cement, the optimum cement and lime combinations (% by weight of dry soil) which resulted in the maximum unconfined compressive strength were: 8:4, 7:2 and 16:2 for the soils from Irbid, Zeizia, and Na'ur respectively as shown in Figure 9.

b) When the alkali additive was added to the optimum combination of cement-lime, the unconfined compressive strength was reduced. The reduction was higher with the increase in the concentration of the chemicals (24). This could be due to the fact that the best combination of cement: lime, the PH value increased substantially, hence most of the soil silica and alumina were dissolved and reacted to form hydrated gels. Thus the incorporation of alkali sodium additives

Figure 9: Effect of lime addition (as a replacer) on the unconfined compressive strength of soil-cement mixtures, cured for 7 days.

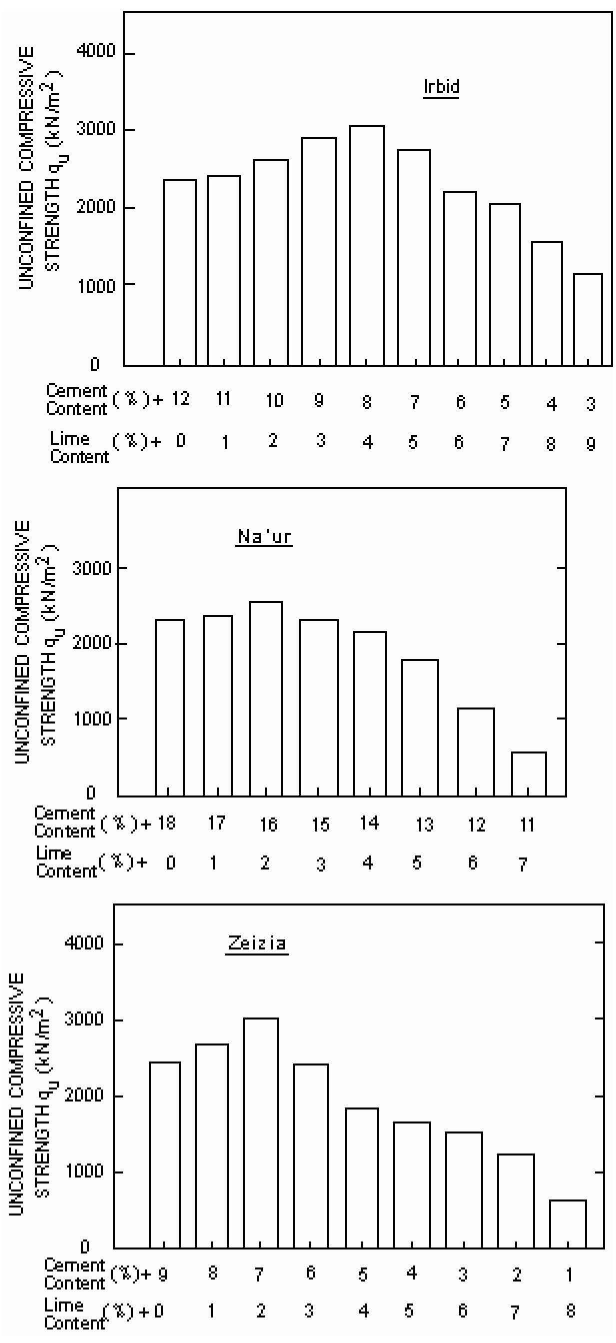
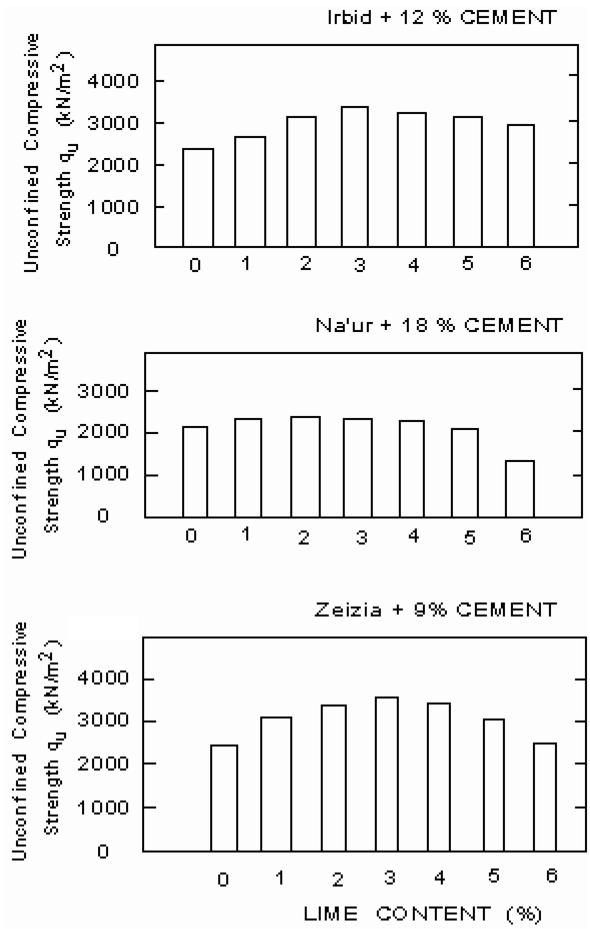


Figure 10: Effect of lime (as an additive) on the unconfined compressive strength of soil stabilized with cement cured for 7 days.



into the mixtures containing the optimum cement-lime combination can not add to the strength of the mixture.

c) If the amount of cement and lime (at the same optimum ratio) is reduced, then the alkali sodium additive is beneficial (24) This indicate that cement and lime content could be reduced by the addition of NaOH or Na_2CO_3 if economically feasible.

d) When lime is used as an additive to soil-cement, it was found that the unconfined compressive strength will increase with the increase in lime content up to about 3% for the three soils when stabilized with the required cement content to meet the citeria, then an increase in lime content will cause a decrease in strength as shown in Figure 10.

4. The C.B.R. tests carried on the soil from Irbid gave the following results:

a) The C.B.R. increases linearly with the cement content, with and without chemical additives. Alkali chemical additives improve the C.B.R. of soil-cement mixtures as shown in Figure 11. The swelling ratio decreased with the increase in cement content. Addition of 3% cement reduced the swelling ratio from 5% to 0.09%.

Figure 11: Effect of cement content on C.B.R. of Irbid soil stabilized with 0.0 N and 0.5 N of chemical additive, cured for 7 days.

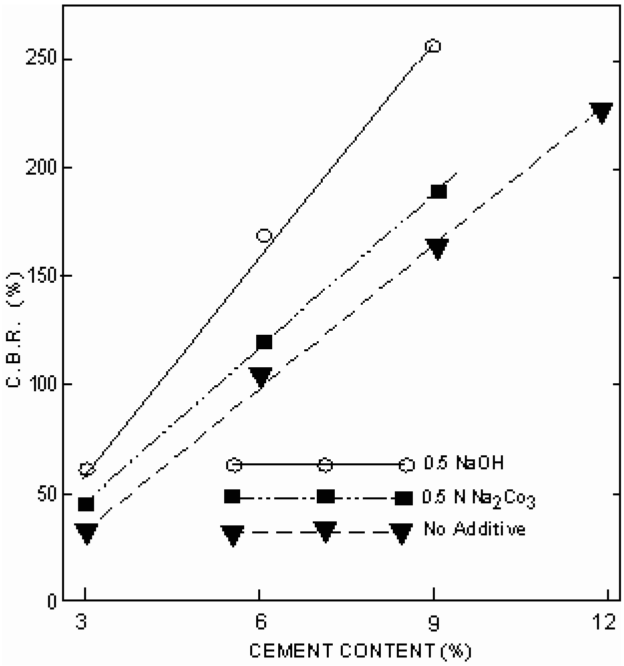


Figure 12: Effect of cement and lime contents on C.B.R. for Irbid soil stabilized with 0.0 N and 1.0 N of chemical additive, cured for 7 days.

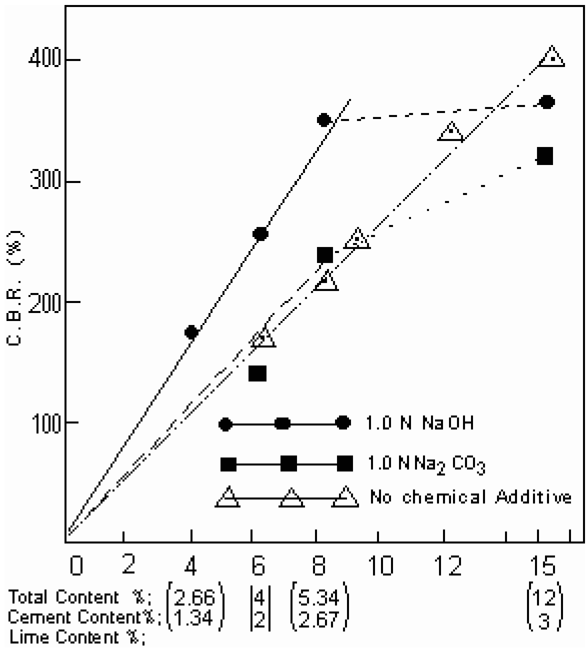
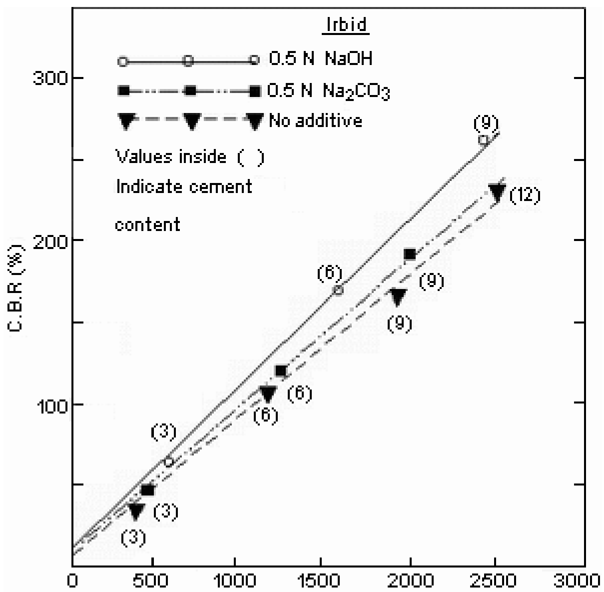


Figure 13: Relationship between the unconfined compressive strength and C.B.R. for Irbid soil-cement mixtures, stabilized with 0.0 N and 0.5 N of chemical additive, cured for 7 days.



b) Addition of 0.5 N alkali sodium additives into the raw soil increased the C.B.R. from 4 to 6% and decreased the swelling ratio from 4.9% to 2.7%.

c) Figure 12 shows the relationship of C.B.R. results with combination of cement and lime with and without alkali sodium additives. The trend of the results is the same as that of the unconfined compressive strength.

d) The C.B.R. results show a linear relationship with the unconfined compressive strength of soil-cement mixtures with and without chemical additives as shown in Figure 13. Hence the unconfined compressive strength could be used to indicate the C.B.R. trends and values.

CONCLUSIONS

Limited to the soils investigated and the test conditions, the following may be concluded.

1. The three soils are regarded as lime reactive. 6 % lime by weight of the soil is the maximum lime content that can be used to improve the strength of the soils under investigation.

2. Soils from Zeizia and Irbid regions can be stabilized using 9% and 12% cement by weight of dry soil respectively. The greenish marly clay from Na'ur region is difficult to stabilize. It requires 18% of sulphate resistance cement.

3. The addition of up to 3% lime to the soil-cement mixture mentioned above improve the strength. In areas where lime is available cheaper then cement, part of the cement content could be replaced by lime to produce the best results. The cementlime ratio were found to be; 7:2, 8:4 and 16:2 for soils from Zeizia, Irbid, and Na'ur respectively.

4. The use of NaOH or Na_2CO_3 solutions of 0.5 N was found to be beneficial for the soil-cement mixtures in the Zeizia and Irbid areas. The alkali additives reduced the strength when added to the soil-cement-lime at the optimum combination reported; but it will be beneficial in reducing the amount of cement-lime (at the same combination ratio). Hence the use of alkali chemical additives depend on the availa-bility of the chemicals and on economical analysis.

5. The results of the C.B.R. tests show a similar trends to that of the unconfined compressive strength. A linear relationship for the soil-cement and soil-cement-lime was found between the unconfined compressive strength and C.B.R. values.

REFERENCES

1. Leonards GA : Foundation Engineering. Chapter 4, McGraw Hill Book Company, 1962.

2. Robert Krebs D and D Richard Walker : Highway Materials. Chapter 8, McGraw Hill Book Company, New York, 1971.

3. Woods KB : Highway Engineering Handbook. Chapter 21, McGraw Hill Book Company, Inc New York, 1960.

4. Ingles OG and JB Metcalf : Soil Stabilization, Principles and Practice. Chapters 1-11, Butterworths, Melbourne, 1972.

5. Spangler MG and RL Handy : Soil Engineering, Chapter 25, Fourth Edition, Harper and Row: Publishers, New York, 1973.

6. Winterkorn HF and Fang HY : Foundation Engineering Handbook. Chapter 8, Vand Nostrand Reinhold Company, New York, 1975.

7. Epps JA, WA Dunlapo, BM Gallawy and DD Currin : Soil Stabilization: A Mission Oriented Approach. Highway Research Board, No 351, pp 1-20.

8. Portland Cement Association : Soil- Cement. Laboratory handbook, Chicago, Illinois, 1956.

9. El-Rawi NM : Strength Characteristics of Soil-Cement Mixtures. Ph D thesis, Oklahoma State University, May 1967.

10. Catton MD : Early Soil-Cement Research and Development. Journal of the Highway Division, ASCE, Vol 85, No HWI, part 1, pp 1-15, Jan 1959.

11. Mills WH : Stabilizing Soils with Portland Cement. Experiments by South Carolina Highway Research Board, No 16, pp 322-349, Nov 1963.

12. Bhatla HS : Soil-Cement, A material of construction for Road and Airfiell> Pavements. Building and Road Research Institute (Ghane Academy of Sciences). Technical Paper No 1, pp 1-47, September 1967.

13. Kezdi A : Stabilized Earth Roads. Chapter 4, Elsevier Scientific Publishing Company, New York, 1979.

14. Oglesby CH and LI Hewes : Highway Engineering. Second Edition, John Wiley and Sons, Inc Page 530-537, New York, 1964.

15. Mateos Manual : Soil lime Research at lowa State University. Journal of soil Mechanics and Foundation Division, ASCE, vol 90, SM, March 1964.

16. Transportation Research Circular : State of the Arts: Lime Stabilization. Properties, Design, Construction, Transportation Research Board No 180, Sept 1976.

17. Marks BD and TA Haliburton : Acceleration of lime-clay Reactions with Salts. Journal of Soil Mechanics and Foundations Division ASCE, vol 98, No SM 4, April 1972.

18. Alawneh BA : Lime stabilization of Cohesive Irbid Soil. M Sc Thesis submitted to Jordan University of Science and Technology, 1989.

19. El-Rawi NM and RN Toma : Investigation of the effect of some chemical additives on the strength of Iraqi Soil-Cement Mixtures. Journal of Building Research Center, Scientific Research Council, Baghdad, Iraq, vol 6, No 2, Nov 1987.

20. El-Rawi NM and M Abdul-Hasan : Effect of chemical Additives on the strength of some Iraqi soils-lime Mixtures. Journal of Building Research center, Scientific Research Council, Baghdad, Iraq, April, 1986.

21. Masannat Y : The use of lime, Cement and Zibar in stabilizing Jordanian soils. Dirasat, A Learned Research Journal, published by the University of Jordan. Vol XV, No 6, June 1988.

22. Thompson MR : Lime Reactivity of Illinois Soils. Journal of the soil Mec., and Found. Division. ASCE Vol 92, No 5, Sep 1966.

23. Moh Za-Chiek : Soil Stabilization with Cement and Sodium Additives. Journal of Soil Mech. and Found. Division, ASCE vol 88, No 6, Dec 1962.

24. Al-Samadi MMY : Optimization of Lime-cement Ratio to stabilize some Jordanian soils using chemical Additives. M Sc. thesis submitted to the College of Engineering University of Baghdad, 1992.

Correspondence:
Nagih M. El-Rawi
College of Engineering,
University of Baghdad,
Baghdad, IRAQ.