International Journal of the Physical Sciences Vol. 6(33), pp. 7614 - 7628, 9 December, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.492
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

Compressibility characteristics of saline soils treated with cement

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Accepted 9 August, 2011

This study investigates the possibility of using high sulphate resisting cement as an additive to control the compressibility behavior of two saline soils sourced brought from Baghdad and Basra governorates in Iraq. The two soils are similar in their constituents, and classified as CL according to Atterberg limit. Standard consolidation samples were prepared from untreated soils, and were treated with 3, 5, 7, and 10% cement by weight and cured for 7, 14, and 21 days. The soil samples were then socked in water and standard consolidation tests were performed on them. Chemical and mineralogical analyses were also carried out before and after the different treatments. The tests results revealed that high sulphate resisting cement successfully influenced the compressibility behavior of both soils. It was observed that the curing period played a major role in reducing the compressibility. Our results also showed that 14 days curing was sufficient for the completion of the major reactions between the cement and the saline soil. The addition of 3% cement by weight to both soils was sufficient to reduce the compression index, C_c, by about 50 to 60% after of 7 days curing. In general both soils exhibited further decrease in the compression index with increasing cement content and curing period. The reduction in compressibility of the treated soils was also accompanied by substantial increase in the modulus of elasticity.

Key words: Compressibility, saline soil, sulphate resisting cement, cement treatment, Iraq.

INTRODUCTION

A saline soil is a non-alkali soil containing soluble salts, mostly sodium chloride (NaCl). Other salts such as chloride, magnesium chloride ($MgCl_2$), potassium chloride (KCl), gypsum ($CaSO_4.2H_2O$), sodium sulphate ($CaSO_4.2H_2O$) and magnesium sulphate ($MgSO_4$) may also be present.

Saline soils are found in the central and southern parts of Iraq, which are mainly arid and semi-arid zones by climatic classification. Generally, the saline soils differ widely in their physical and chemical properties depending on the salt content and type (Buringh, 1960).

Sabkha are silty clay soils with high salt contents, frequently found in arid coastal regions. They are known for their low-bearing strength in their natural condition. Other problems associated with Sabkha soils are: decrease in strength upon wetting, variation of compressibility characteristics of Sabkha sediments, volume change due to the hydration and dehydration of gypsum, and harmful effects of salts present on concrete and steel. The presence of water-soluble salts in soils usually causes severe construction problems especially under wet climatic condition (Al-Qasimi, 1993).

Moreover, the collapse potential of sabkhas presents an unacceptable risk in normal practice and therefore calls for the improvement of its mechanical properties prior to use in any construction work. A review of literature indicates that research work on the stabilization of sabkha is scanty, despite the extensive distribution of sabkha soils worldwide.

Several technique have been proposed for the improvement of the inferior properties of Sabkha soils. This includes: soil replacement, vibratory rolling, pre-loading, deep soil densification using vibroflotation, use of stone columns and dynamic compaction, and chemical

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Figure 1. Provincial saline and water logged soils in Iraq.

stabilization as well as the use of geotextiles (Al-Amoudi, 1995).

Portland cement has been used as an admixture to modify the engineering properties of Sabkha soils. It was found that treatment of Sabkhas with cement increases the compressive strength and penetration resistance. Also, treatment of Sabkha soil with cement decreases the compressibility and increases the stiffness (Al-Qasimi, 1993). It was also reported that the use of cement improved the performance of stabilized sabkha much more than lime, particularly at high moisture contents (Al-Amoudi, 2002).

The beneficial effects of cement treatment on the performance of a broad range of soils have been widely documented (Abboud, 1973; Stipho, 1989; Al-Amoudi, 1994; Al-Amoudi et al., 1995; Uddin et al., 1997; Feng et al., 2001; Lo and Wardani, 2002; Lorenzo and Bergado, 2004; Aiban et al., 2006; Yin et al, 2006; Yong and Ouhadi, 2007; Sariosseiri and Muhunthan, 2009). Cement stabilization is quick, does not need mellowing time, and provides a non-leaching platform, thus the use of cement has certain advantages over other stabilization agents.

This study investigates the capability of high resistance Portland cement as an additive in controlling the compressibility of two Iraqi saline soils.

Saline soils in Iraq

Previous studies carried on Iraqi soils (Dielemen, 1963; Hanna, 1978) confirmed that, most of the Tigris and Euphrates valleys, about 72000 km^2, contained saline soils, concentrated mainly in the middle and south parts of Iraq. About 60% of the soils contain high to medium amounts of salts or they are considered as alkali saline soils. The saline soils in Iraq are divided into:

1. Strongly saline and saline-alkaline soils.
2. Water-logged phase.
3. Saline and saline-alkaline soils.
4. Gulled phase.
5. Associated with non-saline or slightly saline soils.
6. Non-saline and slightly saline soils.
7. Associated with saline and saline-alkali soils.
8. Periodically flooded soils.
9. Non-saline soils.

Figure 1 shows the distribution of the provincial saline and water logged soils in Iraq.

MATERIALS AND METHODS

Two types of saline soils were selected from two sites in Iraq,

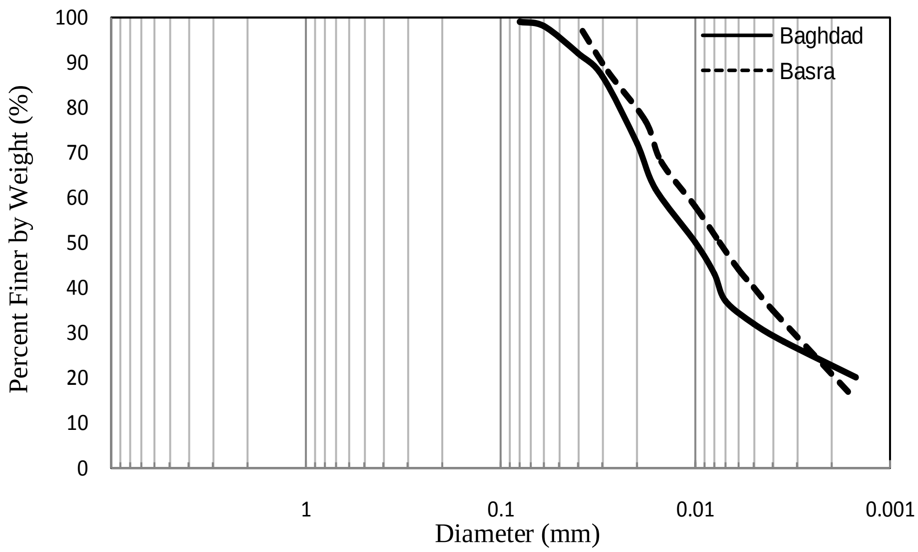

Figure 2. Grain size distribution of soils.

Table 1. Physical and chemical properties of soils.

	Soil location	**Baghdad**	**Basra**
	Atterberg limits		
	Liquid limit (%)	47	46
	Plastic limit (%)	27	24
	Plasticity Index	20	22
	Standard Proctor Compaction:		
Physical properties	Dry density (g/cm^3)	1.63	1.6
	Optimum moisture content (%)	16.3	20
	AASHTO soil classification	A-7-6	A-7-6
	Unified soil classification	ML	CL
	Soil description	Brown clayey silt	Grayey clayey silt
	Specific gravity	2.61	2.71
	pH value	7.6	7.93
	Organic matter content (OM) (%)	0.483	0.73
Chemical properties	Total soluble salts (TSS) (%)	2.05	17.93
	Gypsum content (%)	0.92	17.23
	SO_3 (%)	0.43	8.85

Baghdad governorate in the middle and Basra governorate in the south. Samples for both soils were taken from a depth of about 0.5 m below natural ground surface and was subjected to the necessary physical characterization. The grain size distribution of the two soils is shown in Figure 2. The soils consist of 70 to 75% silt as a major part with clay ranging between 20 to 25%. The physical and chemical properties of soils are shown in Table 1. The mineralogical composition of the soils as detected from the X-ray diffraction is shown in Table 2. Ordinary tap water at room temperature was used in all sample preparation. The additive material used was high sulphate resisting Portland cement with properties indicated in Table 3.

Preparation of soil samples

The collected samples of the two soil types were first dried in oven at 120°C, then graded, pulverized and sieved through sieve No. 14 (1.2 mm) according to the testing specification recommendation by AASHTO M 145 (1991).

The cement were thoroughly mixed with the oven dried samples in 3, 5, 7 and 10% by weigh. Water corresponding to the optimum moisture content was then added gradually to the soil-cement mix and full mixing was carried out until a homogenous wet soil-cement mixture without lumps was achieved. Standard Proctor compaction test was performed for each soil-cement mix and samples, using

Table 2. Mineralogical composition of soils.

Soil location	Components	
Baghdad	Primary components	Calcite, Quartz, Halite
	Secondary components	Feldspar, Kaolinite, Gypsum
Basra	Primary components	Calcite, Quartz
	Secondary components	Anorthite, Kaolinite, Gypsum, Dolomite

Quartz (SiO_2), Anorthite ($Al_2.SiO_2$), Gypsum ($CaMg(CO_3)_2$), Feldspar ($Na.Al.SiO_3.O_8$), Calcite ($CaCO_3$), Halite (NaCl), Kaolinite ($Al_2Si_2O_5(OH)_4$)

Table 3. Cement properties (Type V) according to ASTM Standard.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MaO	SO_3
Chemical composition	19.28%	4.75%	6.33%	62.50%	2.51%	1.94%

	C_3S	C_2S	C_3A	C_4AF
Mineralogical composition	66.82%	5.22%	1.89%	19.24%

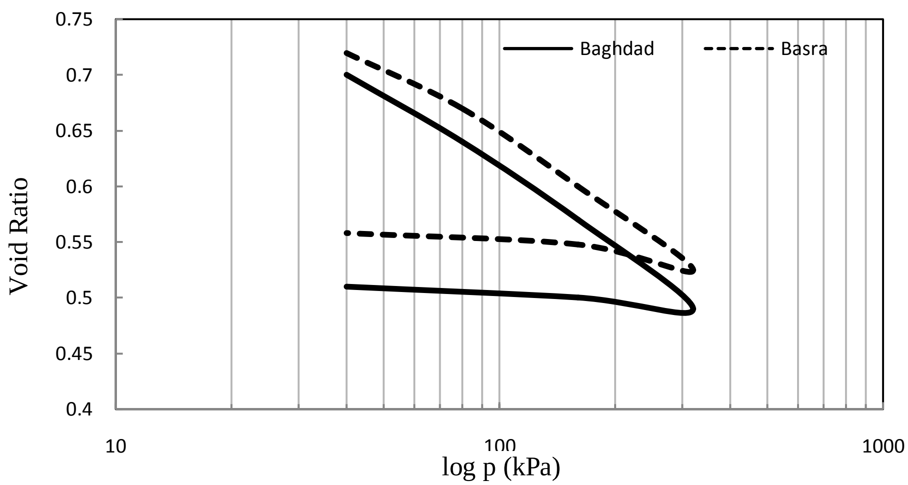

Figure 3. Void ratio versus log p (applied pressure) for untreated soils.

consolidation rings, 75 mm in diameter and 19 mm in height, were extracted from the compaction mould.

The rings with compacted soil-cement mixture were tested in standard odometers either immediately or after curing for 7, 14 and 21 days. At the end of the respective curing periods, the samples were weighted again and placed into the odometers apparatus for consolidation test. The temperature was recorded during the curing period.

RESULTS AND DISCUSSION

Compressibility on untreated saline soils

The results of the variation of the logarithm of the applied stresses versus the void ratio are presented in Figure 3. The figure revealed the values of compression indices of 0.25 and 0.133 for Baghdad and Basra, respectively, and a swelling indices of 0.017 and 0.033, respectively.

Figure 4, 5 and 6 shows the variation of the coefficient of compressibility, a_v, coefficient of volume change, m_v, and the constrained modulus, D, respectively, with the applied pressure. These results represent typical relationships for untreated Baghdad and Basra saline soils.

Compressibility of cement-treated saline soils

Figures 7, 8 and 9 shows the variation of the compression index, C_c, swelling index, C_s, and the compression ratio, $C_c/(1+e_o)$, with cement content. All the figures show a decreasing trend of the parameters

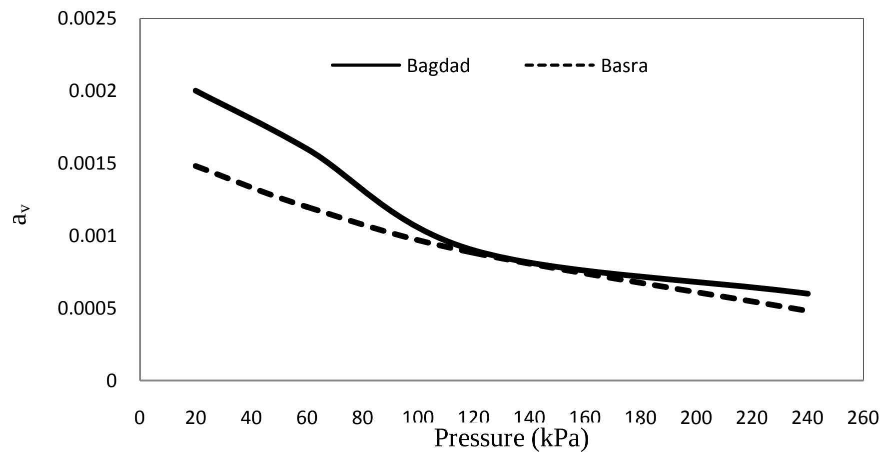

Figure 4. Coefficient of compressibility versus applied pressure.

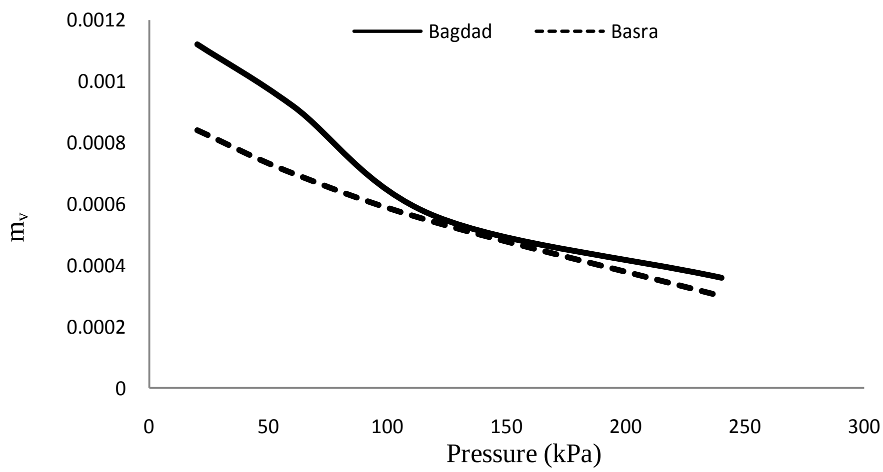

Figure 5. Coefficient of volume change versus applied pressure.

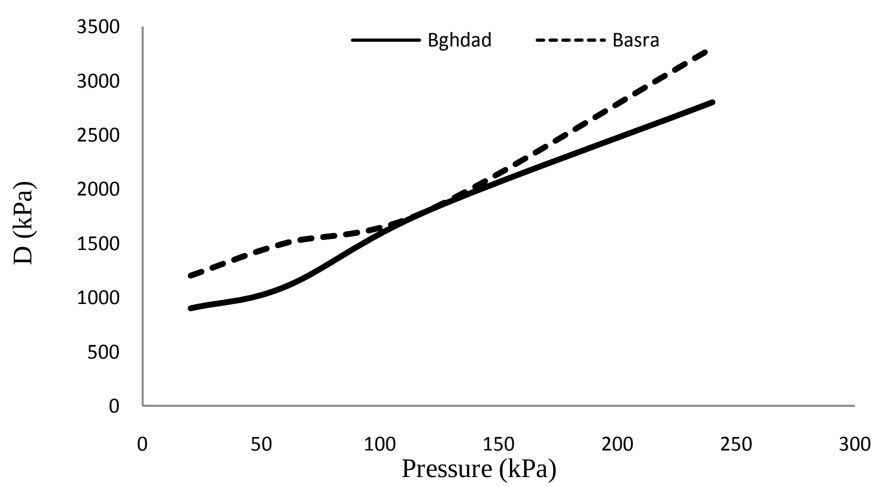

Figure 6. Constrained modulus versus applied pressure.

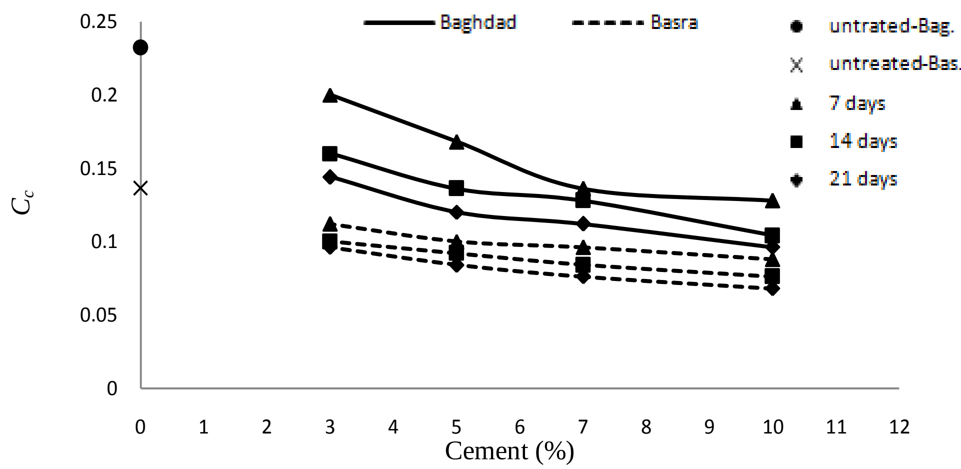

Figure 7. Compression index versus cement content.

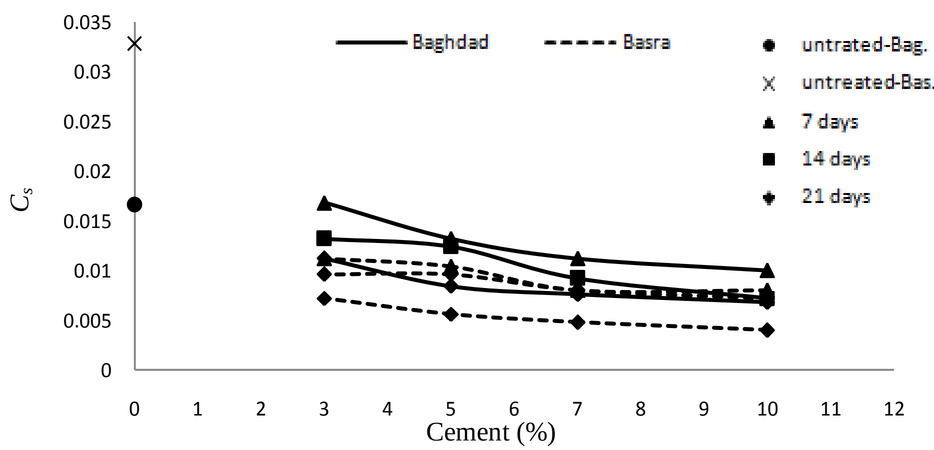

Figure 8. Swelling index versus cement content.

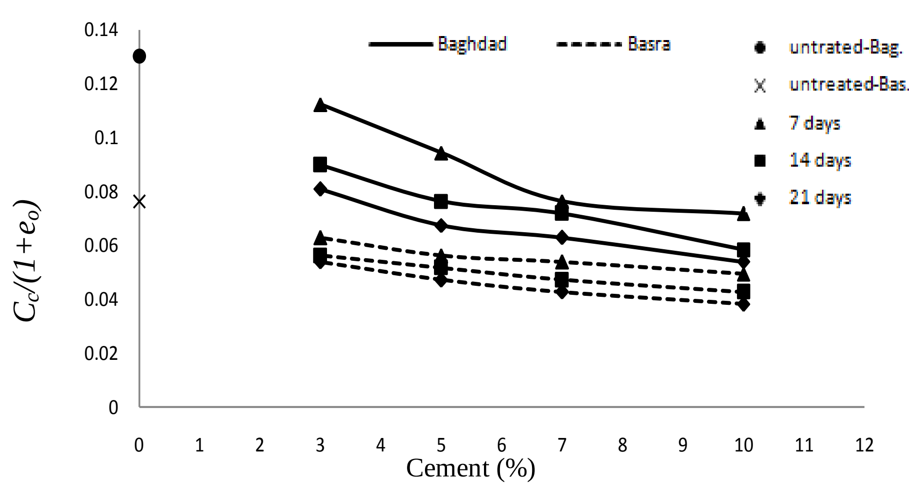

Figure 9. Compression ratio versus cement content.

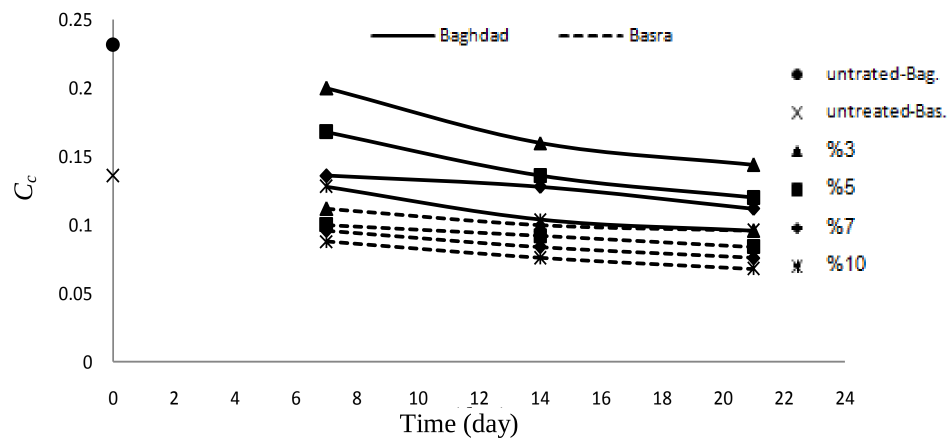

Figure 10. Compression index versus time.

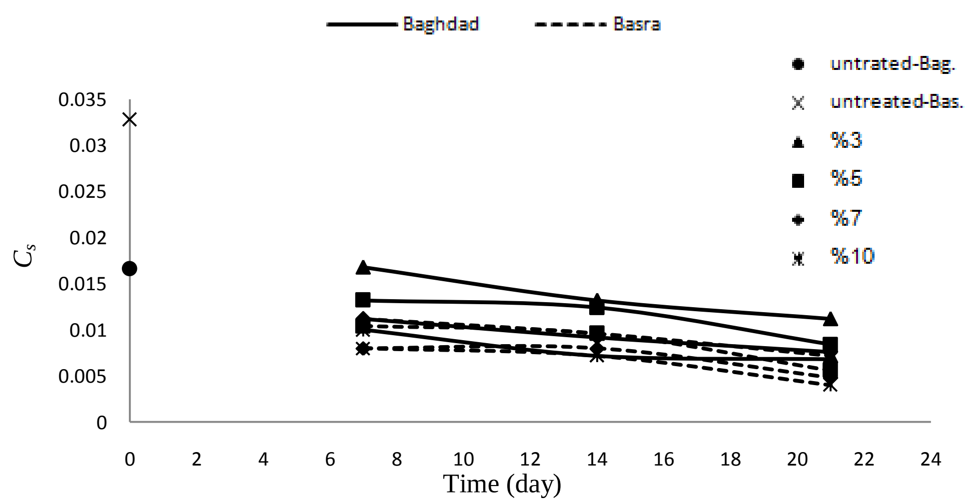

Figure 11. Swelling index versus time.

with increasing cement content. Figure 7 showed a sharp decrease in compression index, C_c when the cement content increased from 3 to 10 %.

The rate of change of compression index, C_c, with cement content is higher in the sample cured for 7 days and it was observed to increase as the curing days increased, that is, 14 and 21 days (Figure 7). The same behavior is noticed for the swelling index, C_s, and the compression ratio, $C_c/(1+e_o)$ (Figure 8 and 9, respectively).

Figure 10 indicates that the cement proportion in the Baghdad soil sample was 3%, a pronounced decrease in the compression index, C_c, was observed as curing period increased from 7 to 21 days. The effect becomes marginal when the cement content is increased to 10%. Thus, Figure 10 shows that C_c decreased sharply after 7 days. For curing period of 21 days, the decrease in C_c was less pronounced.

The same behavior can be seen in Figure 11 for the swelling index, C_s, and also for the compression ratio, $C_c/(1+e_o)$ as shown in Figure 12.

It is worth mentioning that increasing the cement content with shorter curing period will provide better results than decreasing the cement content and increasing the curing period.

To demonstrate the effect of cement content and curing period on the coefficient of compressibility, a_v, Figures 13, 14 and 15 is plotted showing a_v versus cement content at different consolidation pressures for 7, 14 and 21 days curing time, respectively.

All the figures demonstrated that the addition of cement in the range of 3 to 10% causes a sharp decrease in a_v at low consolidation pressure (p=40 kPa), the effect of cement becomes less significant when the samples were subjected to 320 kPa and cured for 21 days.

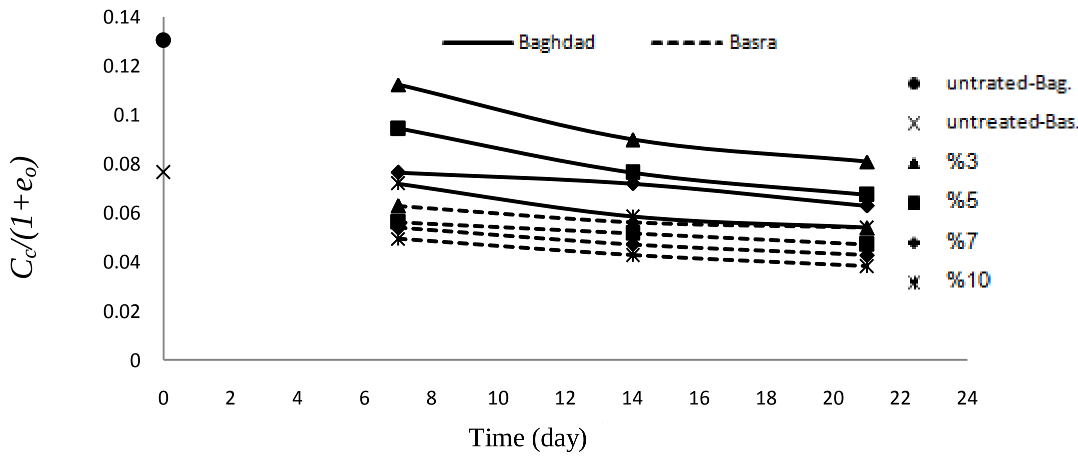

Figure 12. Compression ratio versus time.

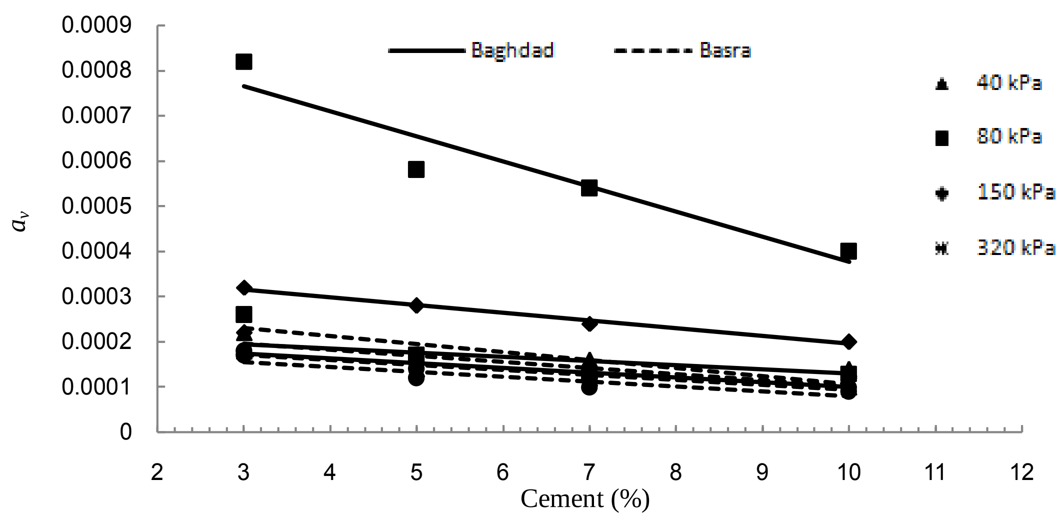

Figure 13. Coefficient of compressibility versus cement content for 7 days curing period.

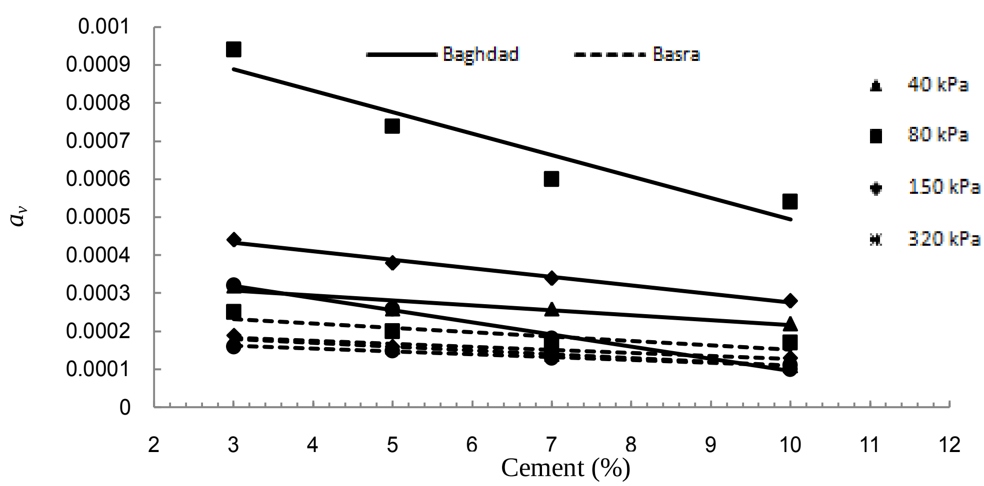

Figure 14. Coefficient of compressibility versus cement content for 14 days curing period.

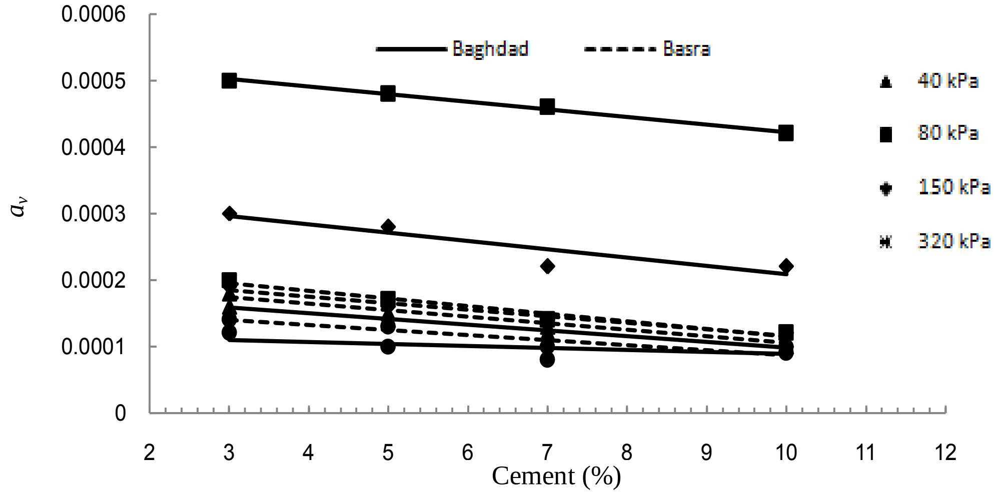

Figure 15. Coefficient of compressibility versus cement content for 21 days curing period.

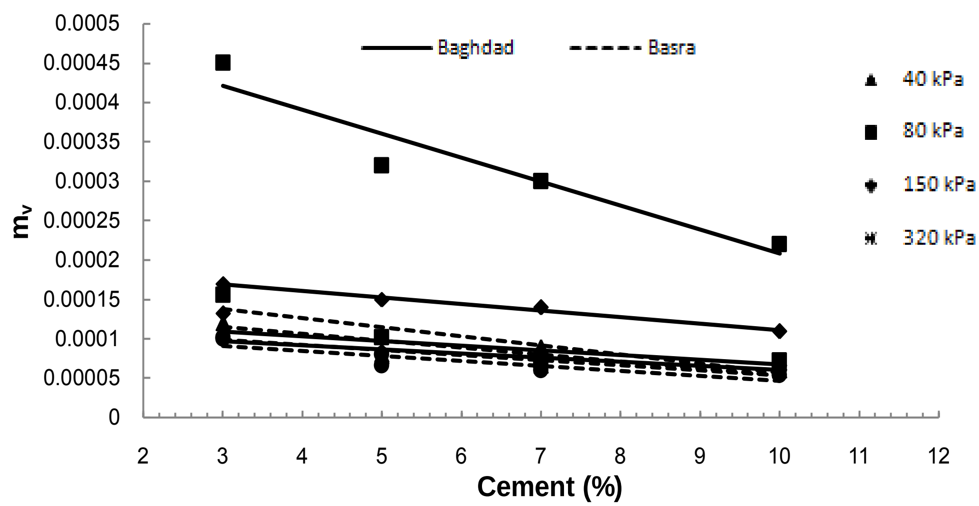

Figure 16. Coefficient of volume change versus cement content for 7 days curing period.

To explain this behavior, it is believed that at higher stress levels, the particles of the untreated saline soil are compressed to closer state even at low stress level. Any addition of cement irrespective of the amount will provide additional bonding between the particles that will increase the stiffness of the saline soil, generating greater resistance to deformation which increases with time. The effect of cement content is more visible at low stress levels and shorter curing periods.

Figures 16, 17, 18, 19, 20 and 21 illustrate, respectively, the variation of the coefficient of volume change m_v and the constrained modulus of elasticity, D (the reciprocal of the coefficient of volume change m_v) with cement content for samples curried for 7, 14 and 21 days.

Similar to the compression index, a_v, and the coefficient of compressibility, C_c, the coefficient of volume change, m_v, exhibited a decreasing trend with increasing cement content. Again, the rate of change of volume change, m_v, versus cement content is more pronounced at low stress level (p=40 kPa) and shorter curing period. Figures 19, 20 and 21, clearly indicates an increasing trend of the constrained modulus of elasticity, D, with increasing cement content. The shorter curing period of 7 days illustrates a sharp steady increase in the constrained modulus of elasticity with increasing cement content irrespective of the applied pressure. On the other hand, for 14 days curing period, the sharp increase in the constrained modulus was only observed at high stress level of 320 kPa, while the other stress levels demonstrated

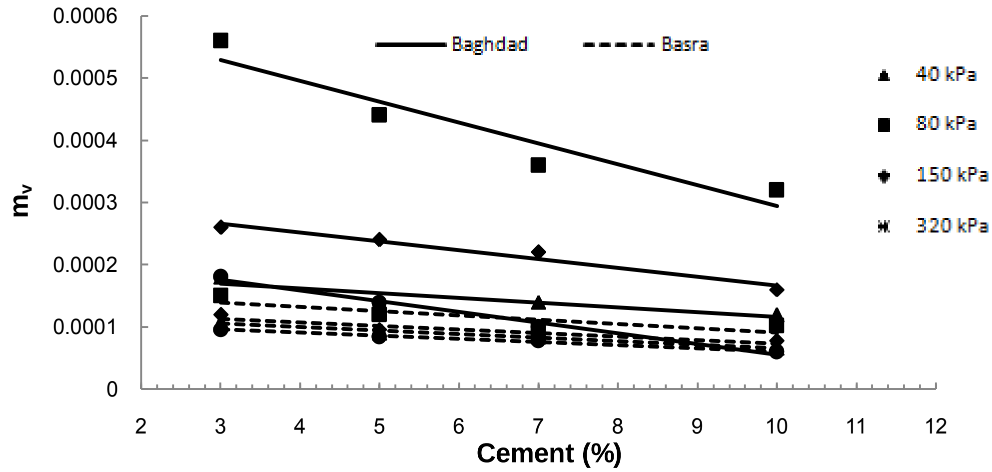

Figure 17. Coefficient of volume change versus cement content for 14 days curing period.

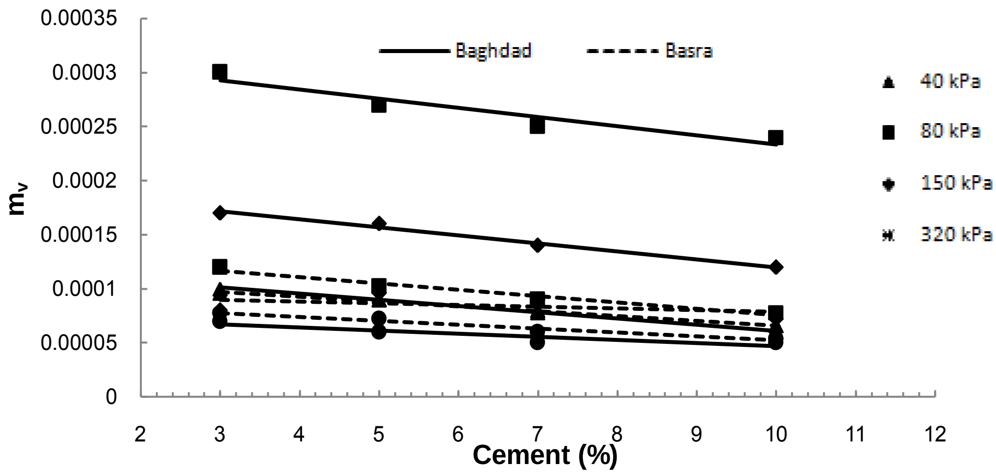

Figure 18. Coefficient of volume change versus cement content for 21 days curing period.

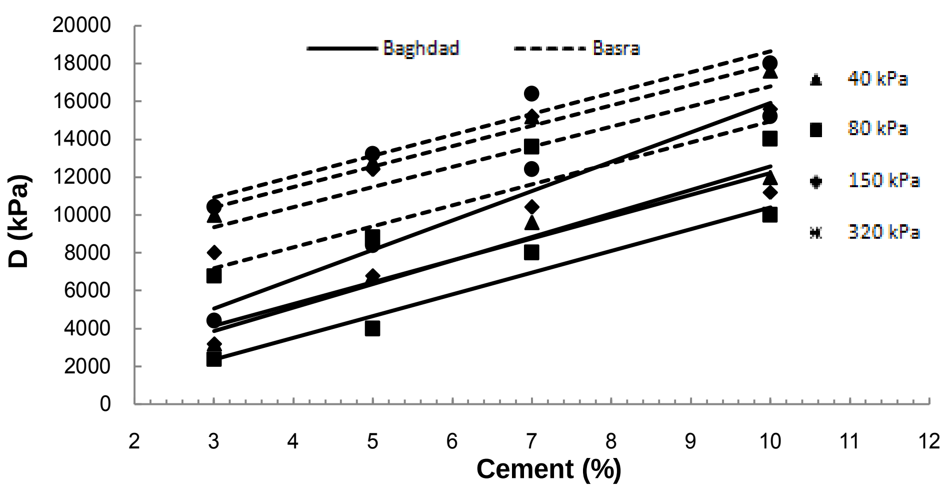

Figure 19. Concentrated modulus versus cement content for 7 days curing period.

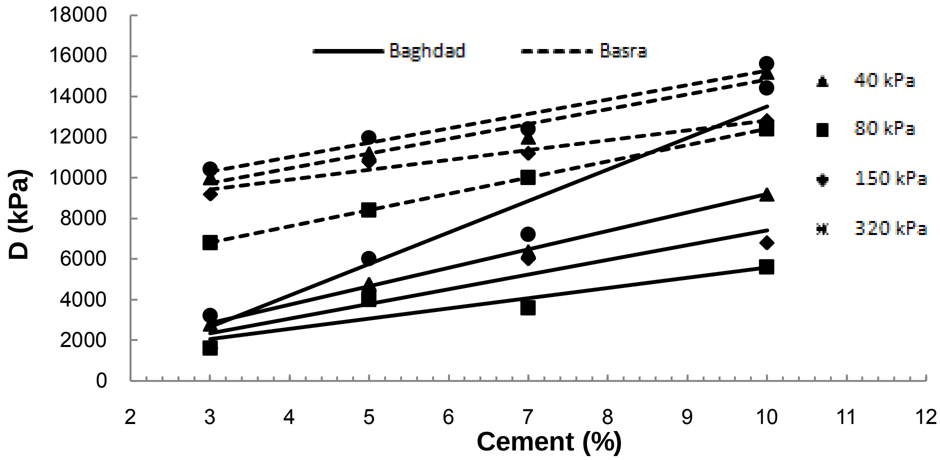

Figure 20. Concentrated modulus versus cement content for 14 days curing period.

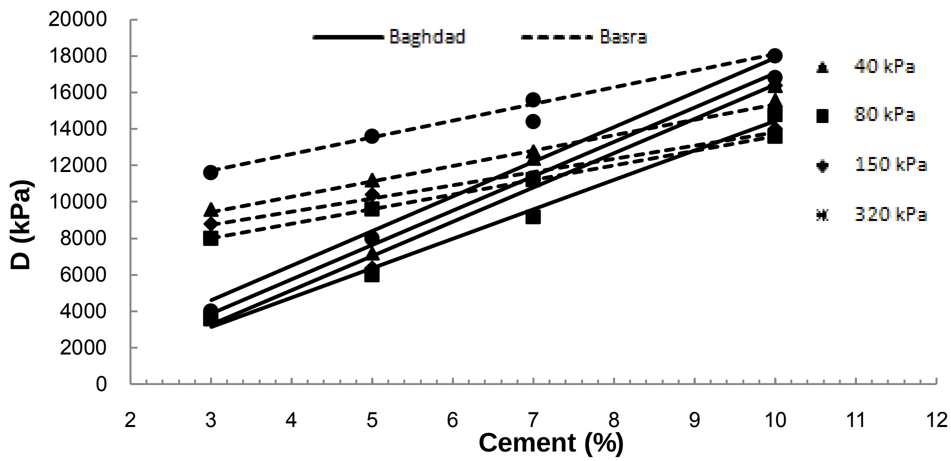

Figure 21. Concentrated modulus versus cement content for 21 days curing period.

Table 4. The mineralogical composition of Baghdad soil.

Untreated soil	Primary component Secondary components	Calcite, Quartz, Halite Feldspar, Kaolinite, Gypsum
Treated with 10% cement and cured for 21 days	Primary components Secondary components Calcium Silicate ($CaSiO_3$)	Calcite, Quartz Feldspar, Kaolinite C_3S, C_2S, C_2SH, Ettringite

only little increase in the constrained modulus with increasing cement content.

Compressibility of saline soil on the light of mineralogical and chemical analysis

The saline soil brought from Baghdad was thoroughly investigated through a series of X-ray diffraction and chemical analysis before and after treatment with cement. The cases covered in the X-ray tests are for the untreated saline soil and soil treated with 10% cement and cured for 21 days.

Table 4 illustrates the results of the X-ray diffraction for both treated and untreated saline soil. The untreated saline soil demonstrates the components shown in Table 2 and reproduced in Table 4 which consist mainly of calsite ($CaCO_3$), quartz (SiO_2), halite (NaCl) as primary

Table 5. Chemical properties of Baghdad soil (untreated and treated).

Baghdad		pH	SO_3 (%)	TSS (%)	Gypsum (%)	OM (%)
untreated		**7.6**	**0.43**	**2.05**	**0.92**	**0.483**
3% cement	7 days	11.1	0.6	1.71	1.29	0.524
	14 days	9.7	0.4	2.44	0.86	0.55
	21 days	9.5	0.42	2.3	0.9	0.52
7% cement	7 days	11.7	1.22	2.33	2.62	0.545
	14 days	11.2	0.9	2.69	1.94	0.55
	21 days	11.0	0.8	2.6	1.72	0.57
10% cement	7 days	11.8	1.42	2.53	3.05	0.593
	14 days	11.2	0.86	1.62	1.85	0.56
	21 days	11.4	1.16	2.6	2.49	0.59

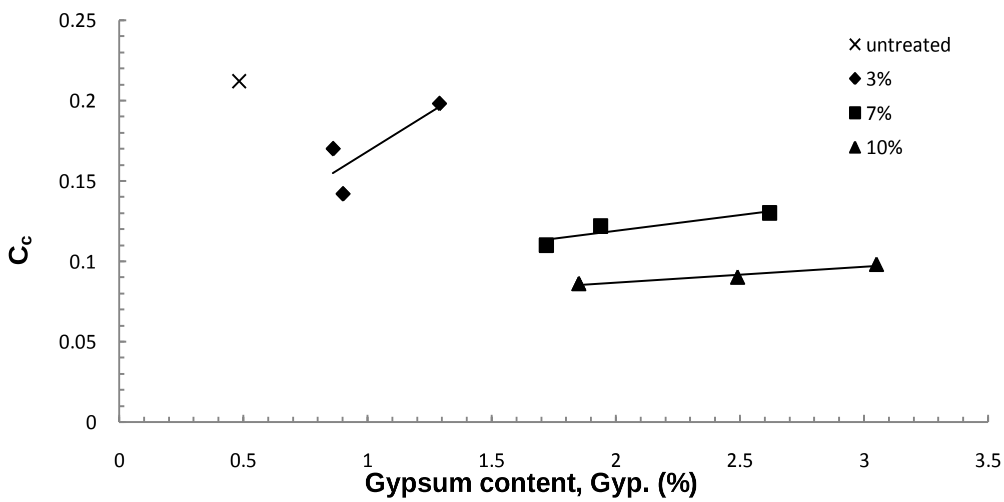

Figure 22. Compression index versus gypsum content.

components and feldspar ($Na.Al.SiO_2.O_8$), kaolinite ($Al_2.SiO_2.O_5(OH)_4$), gypsum ($CaSO_4.2H_2O$) as secondary components.

Also, Table 4 illustrates the mineralogical composition of Baghdad saline soil treated with 10% cement and cured for 21 days, the qualitative results show the disappearance of both gypsum ($CaSO_4.2H_2O$) and halite (NaCl) and appearance of anorthite and calcium silicate ($CaSiO_3$).

On the light of chemical analysis shown in Table 5, the following relationships are drawn relating the compression index, C_c, versus gypsum content, organic matter, OM, total soluble salts, TSS, pH value and sulphate content,SO_3.

Figure 22 shows the combined effect of cement content and curing time on the gypsum content. The addition of cement will initially increase the gypsum content then it decreases with time probably due to some chemical reactions that occur with time.

The organic material content, OM, did not show any response to the addition of cement and its values fluctuated between 0.48 for the untreated saline soil to 0.59 when the saline soil was treated with 10% cement and cured for 7 days as shown in Figure 23. This scattering in the values of the organic content is rather marginal and has no influence on the compressibility.

The compression index, C_c, is plotted versus the total soluble salts (TSS) (Figure 24). The results did not show any clear correlation between the C_c and the TSS. It can only be stated that with 10% cement content, the TSS did not show any effect on the compression index.

Figure 25 demonstrates the effect of cement content and curing time on C_c and pH values. Increasing cement content from 3 to 10% causes a sharp decrease in the

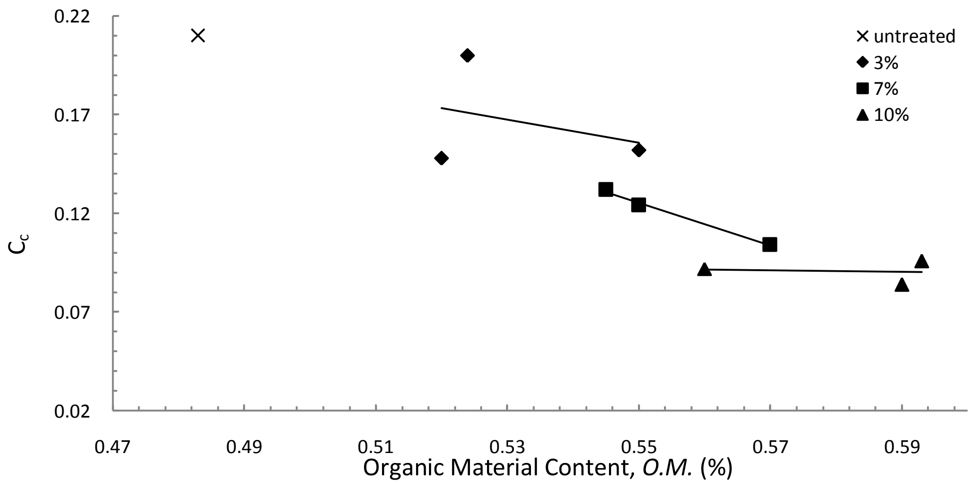

Figure 23. Compression index versus organic material content.

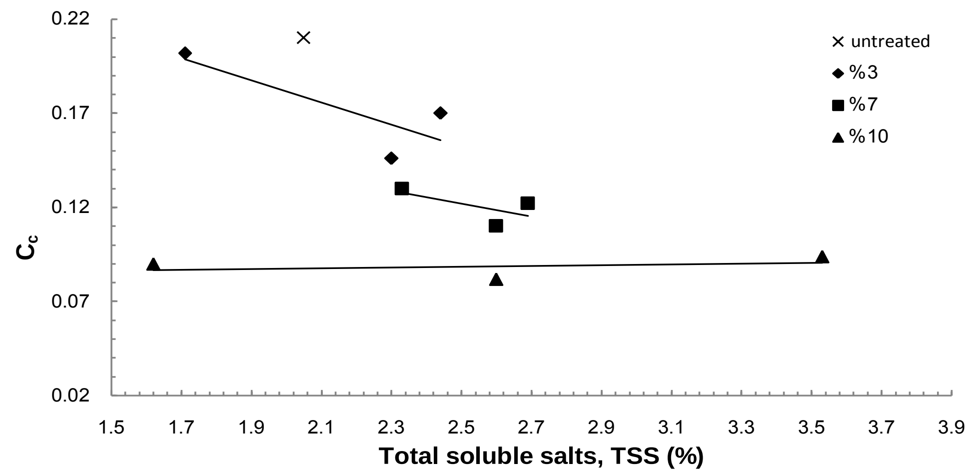

Figure 24. Compression index versus total soluble salts.

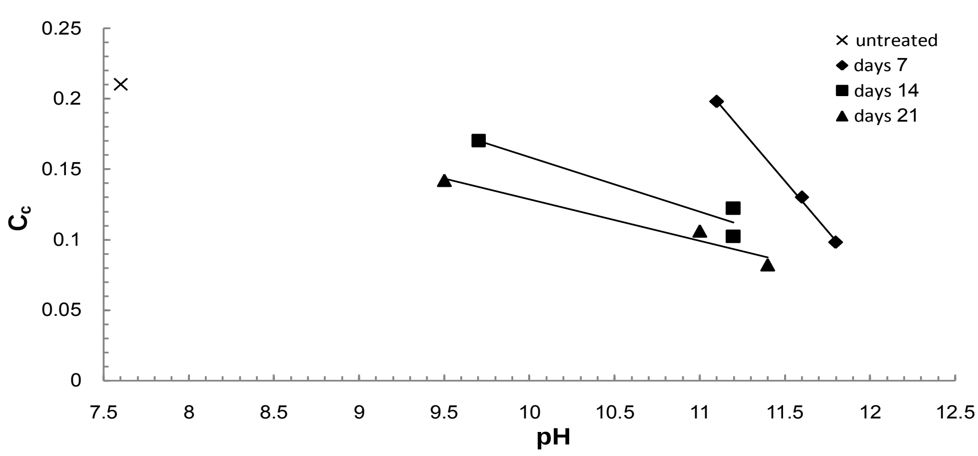

Figure 25. Compression index versus pH value.

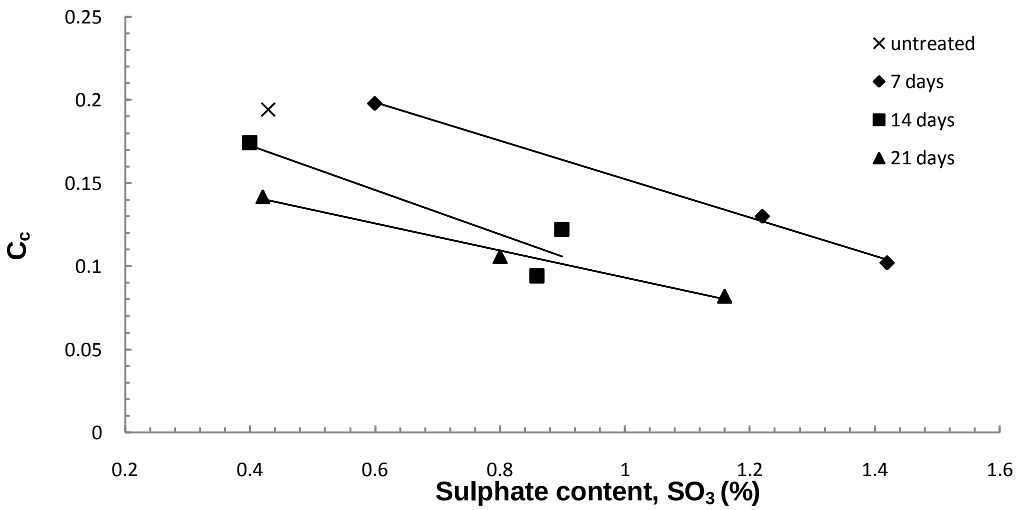

Figure 26. Compression index versus sulphate content.

compression index, C_c, accompanied by a slight increase in pH value from 11 to 11.75 for 7 days curing time. With increasing curing period, the pH value decreases consistently with increasing cement content. This indicates that there is a chemical reaction taking place during the curing period that causes this decrease in the pH value.

The same discussion is applied for the variation of sulphate (SO_3) with cement content and curing period. The compression index, C_c, decreases with increasing curing period for any specific cement content. Also, for any specific curing period, the compression index, C_c, decreases with increasing cement content and ultimately increasing the sulphate (SO_3) that can be considered in Figure 26.

To highlight the effect of the two hardening parameters (cement content and curing period) on the compressibility of the cement-treated saline soils, it can be stated that gradual hardening of clay accompanied by a reduction of compressibility is quite remarkable, when the curing period is kept constant and the cement content increases from 3 to 10%.

On the other hand, when the cement content is held constant and the curing period is increased, the compressibility is improved rapidly within the 14 days curing period, following that the curing period did not provide any further significant reduction in compressibility.

From such behavior, it can be deduced that the cement content is the more dominating parameter than curing period which is a secondary and auxiliary parameter of cement content. Similar results were concluded by Uddin et al. (1997).

Conclusion

The effect of using high sulphate resisting cement as an additive to control the compressibility of two saline soils brought from Baghdad and Basra governorates in Iraq was investigated in this paper. The following conclusions are based on the data and discussions presented in the previous paragraphs.

The compressibility characteristic, C_c, C_s, m_v, and D of the two saline soils from Baghdad and Basra have shown a significant improvement by the addition of high sulphate cement.

There are two hardening parameters that affects the compressibility, are the cement content and the curing period.

The compression index, C_c, decreases with increasing pH value and sulphate content (SO_3%) accompanied by increasing the cement content. Increasing the curing period revealed a decrease in the rate of change of the compression index, C_c, with pH value and sulphate content (SO_3%).

The swelling index, C_s, for two soils ranged between 0.02-0.007 for untreated soils and decreased to 0.015-0.005 for treated soils.

The mineralogical analysis of Baghdad soil treated with 10% cement and cured for 21 days revealed the complete disappearance of both gypsum and halite. The combined effect of cement content and curing period caused a decrease in gypsum content with increasing curing period for any particular cement content.

About 50-60% reduction in the compression index, C_c, or the compression ratio, $C_c/(1+e_o)$, was noticed when Basra saline soil was treated with 3% cement and cured for 7 days. A better response was noticed for 14 and 21 days curing period with increasing cement content.

ACKNOWLEDGEMENTS

The authors would like to thank all of the engineering staff at the National Center for Construction laboratories and Research (NCCLR) in Iraq, the Geological Survey and Mining laboratory and the Soil Laboratory of the University of Technology, and the College of Agriculture of the University of Baghdad for their great help and support in conducting the required soil tests and X-ray.

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