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Improvement of Volume Change Characteristics of Saline Clayey Soils

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Abstract: Saline soils are of challengeable soils that may cause many problems in civil engineering projects. In this study, volume change behaviour of saline soils and also the effect of improvement and reinforcement on them have been investigated using laboratory tests as well as consolidation test, swelling pressure test and free swelling test. The case study is Amirkabir Highway which connects the cities Qom and Kashan. Fifty four kilometer of this highway was deformed like waves due to existence of saline soils. The laboratory investigations showed that the studied soil has a considerable swelling potential which appears to be the main cause of damage to the highway pavement, therefore it is decided on improving the subsoil condition. The research program comprises of studying volume change behavior of saline soil, stabilized with lime and resin-epoxy polymer and reinforced with polypropylene fiber. Afterwards, the results of two cases of stabilized and non-stabilized samples have been compared. According to the results, the main cause of swelling is soil disturbance and structure destruction of initial soil composition. Considering all of test conditions, it is appeared that, although lime is a traditional stabilization material but it is economic for the most geotechnical projects and usage of polymer is suggested only in special applications due to its rapid setting.

Key words: Saline clayey soil, swelling potential, lime, epoxy–resin polymer, polypropylene fiber

INTRODUCTION

Saline soils are of challengeable soils that may cause many problems in civil and geotechnical engineering projects (Fang, 1991). Many studies have been conducted for determining geotechnical properties of saline soils all over the world. Saline soils have some unfavorable properties such as high compressibility, low bearing capacity and swelling capability (Ashayeri and Shahabadin, 2004; Al-Zoubi, 2008; Foncea *et al.*, 2005). Considering excessive development of urban area and also highways and road networks which are necessary for transportation, civil engineers have to construct significant plans possibly over saline soils. For the first time, in 1938 U.S Earth Reform Bureau introduced soil swelling from soil mechanics view point (Foncea *et al.*, 2005). Damages from expansive soils in civil constructs (e.g. buildings, roads, superstructures, etc.) have been reported all over the world (Kehl, 2006). Estimated damages by these soils exceed billion dollars, annually. Nevertheless, a few researches have been investigated on the stabilization and reinforcement or improvement of these soils. Because saline soils spread over large parts of Iran and regarding to indispensable construction of structures like roads and highways over these soils, our effort in this study was firstly to investigate volume change behaviour and thereafter improvement of swelling properties of these soils by stabilization and reinforcement.

LOCATION OF THE STUDIED AREA

The case study of this research is located in 54 km of Amir Kabir Highway that is located between Qom and Kashan cities in Iran. In this part of highway, the pavement is distorted excessively. Considering several pavement repairs have done, it was observed that over a period of time (a few months) and by commence of the spring season wavy shape deformation was appeared in the surface of the road. By field investigation it was specified that the subsoil structure is composed from saline soils and also surface flow of seasonal water exist at this portion of highway which makes this condition even worse. Figure 1a and b, show the salinity of local soils. After preliminary studies and field investigation, soil of this place selected for our study.

SAMPLING AND *IN SITU* TESTS

After elementary studies and field investigation and site selection, disturbed and undisturbed sampling

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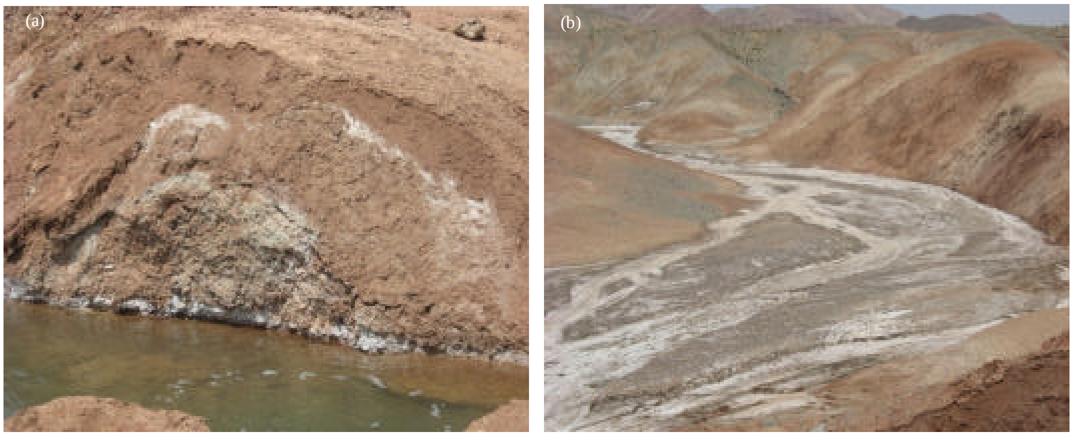

Fig. 1: Salinity of local soil's surface of studied area

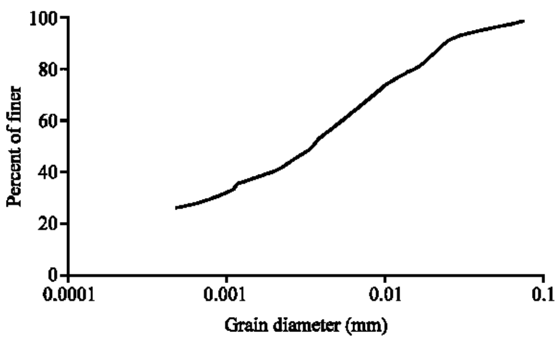

Fig. 2: Particle size distribution curve

Table 1: Results of *in situ* tests

Wet density (γ_{wet}) (g cm^{-3})	Dry unit weight (γ_{wet}) (g cm^{-3})	Moisture content (%)	N_{SPT}
2.12	1.86	16.5	39

Table 2: Properties of studied soil

Gs	LL	PL	PI	USCS Classification	pH	EC*	TDS**
2.73	41	22	19	CL	7.80	83.38	8.02

*Electrical conductivity; **Total dissolved salt

implemented by drilling two Test pit with the height of 2.5 m and also some tests like *in situ* density and SPT had been conducted and their results had been reported in Table 1. This study started on September 2008 and lasts up to February 2010.

The studied soil recognized as saline soil. After sampling from selected site, preliminary tests such as particle size analysis, hydrometry, Atterberg limits and soil chemistry had been conducted. The studied soil was classified as low plasticity clay, i.e., CL. Other properties are listed in Table 2 and particle size distribution curve is shown in Fig. 2.

CHARACTERISTICS OF APPLIED STABILIZERS AND REINFORCEMENT AGENTS

In the current study, lime selected as a traditional stabilizer, resin-epoxy polymer selected as a non-traditional stabilizer and polypropylene fibers used as a reinforcement equipment.

Lime: Lime as a stabilizer is researched through many research works (Amu *et al*., 2008; Faluyi and Amu, 2005). In this study hydrated lime was used as a traditional stabilizer. Caustic lime did not use in this study. Although, it is more effective in stabilization due to its high content of CaO which has more influence on stabilizing and improvement of soil with respect to hydrated or slaked lime. But, since working with hydrated lime is more secure and its application is more been selected, hydrated lime was preferred. Caustic lime in comparison with slaked lime has more volume change; by average volume change of caustic lime relative to slaked lime is 2.5 to 3 times (Al-Rawas *et al*., 2005). Applied lime in this study was hydrated lime with pH of 12.52 and original specific gravity of 560 kg m^{-3} and particle density of 2.32 that more than 90% of this lime is $Ca(OH)_2$. In this study, due to special condition of soil and more effectiveness, lower percents of hydrated lime (2, 4 and 6%) have been used for the tests.

Resin-epoxy polymer: Resin-epoxy polymer is a non water–based polymer and in contrast with water-based polymers where in contact with water loss their strength. This polymer is water resistant and this property is one of the main reasons for selection of this polymer as a stabilizer in our research. Since, saline soils in contact to water loss considerable strength, using water-based polymer in this study was unfavorable.

Table 3: Characteristics of applied resin-epoxy polymer

Chemical compound	$C_3H_5O\,[C_{18}H_{19}O_3]_nC_{18}H_{19}O_3$
Density (g cm^{-3})	2.2
Modulus of elasticity (Gpa)	20
Melting point	More than 200°C

Table 4: Polypropylene fiber properties that used in study

Melting point	Tensile strength	Diameter	Length	Specific weight	Chemical base	Appearance
160°C	350 N mm^{-2}	20 µ	14 mm	900 kg cm^{-3}	Polypropylene	White colour

Fig. 3: Polypropylene fiber used in this study

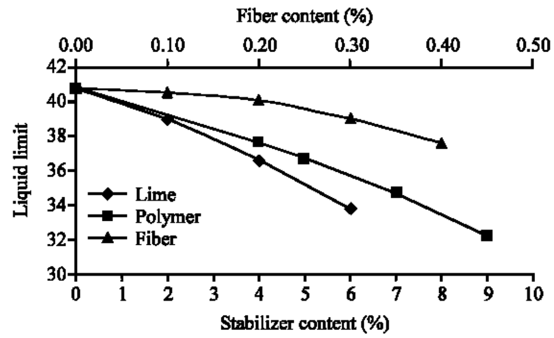

Fig. 4: Influence of adding stabilizer and reinforcement material over liquid limit

In this study, polyamide was used as hardening agent that base on previous experience and small particle size of the soil, 1:0.9 ratio of polymer to hardening agent was selected. Table 3, shows some characteristics of resin-epoxy which is used in this research. For obtaining appropriate amount of stabilizer, different weight percent of resin-epoxy polymer added to the soil and their results was investigated. Results showed that polymer in weight percent lower than 4 cannot sustain soil particles in prepared samples. Because of this fact four levels of percent have been used (4, 5, 7 and 9%).

Polypropylene fiber: Fiber that was used in this study classifies as a fiber with chemical base of polypropylene polymer (Abdi and Ibrahimi, 2003). According to the previous researches about soil reinforcement with polypropylene fiber, this fiber as an economic reinforcement material was used for many improvements of mechanical characteristics of soils. Appearance of this fiber is shown in Fig. 3.

Table 4, shows the properties of polypropylene fiber used in this study. According to literature review, based on special conditions of soil and also more effectiveness, typical percent, i.e., 0.1-0.4% range have been selected (0.1, 0.2, 0.3 and 0.4%).

EXPERIMENTAL PROCEDURE

In this study, volume change behaviour of disturbed, undisturbed, stabilized samples with lime and resin-epoxy polymer and also reinforced samples with polypropylene fiber were compared with each other. After implementation compaction test on natural soil, this test conducted over stabilized samples with 2, 4 and 6% lime and samples with 0.1, 0.2, 0.3 and 0.4% polypropylene fiber. These values are used for preparing undisturbed samples. Experimental procedure includes Atterberg limit tests, compaction tests, swelling potential tests and consolidation tests.

Atterberg limits tests: Here, experimental results of liquid and plastic limits for stabilized soil with lime and polymer and also reinforced soil with polypropylene fiber have been reported. Results show that both stabilizers (lime and polymer) and also polypropylene fiber as reinforcement material reduce the liquid limit of soil, as shown in Fig. 4. As could be seen from Fig. 4, adding lime and polymer to soil reduce liquid limit more than adding polypropylene fiber.

Plastic limit determination test for soil and polymer mixture was impossible because wicking of this mixture was not feasible. The results of plastic determination test for soil and lime mixture show that adding lime increases plastic limit of the soil. As shown in Fig. 5, plastic limit changes of soil and polypropylene fiber mixture in comparison with soil and lime mixture is very low, therefore plastic limit increase till reach 0.2% and from 0.2 to 0.4% of polypropylene fiber, it will decrease. Plastic index in both mixtures has been decreased. As shown in Fig. 6, decreasing rate of plastic index in soil and lime mixture is more than soil and polypropylene fiber mixture. The results have a good agreement with the results of Raymond and Ouhadi (2007).

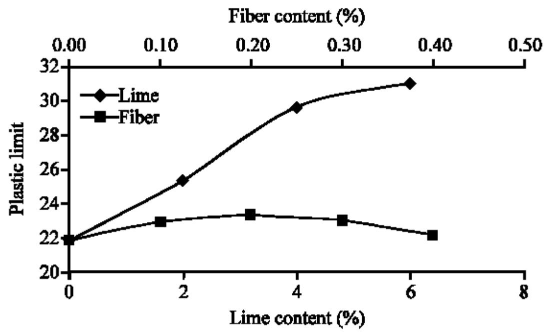

Fig. 5: Effect of adding lime and polypropylene fiber on plastic limit of soil

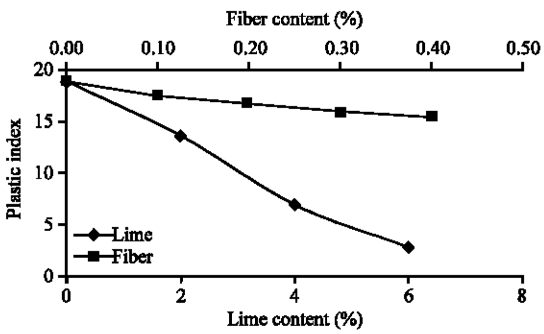

Fig. 6: Effect of adding lime and polypropylene fiber on plasticity index of soil

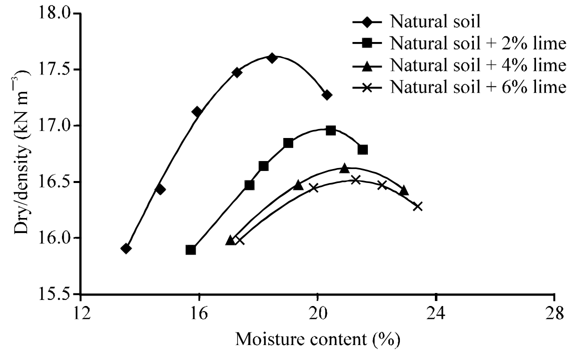

Fig. 7: Compaction test results on natural soil and mixture of natural soil and lime

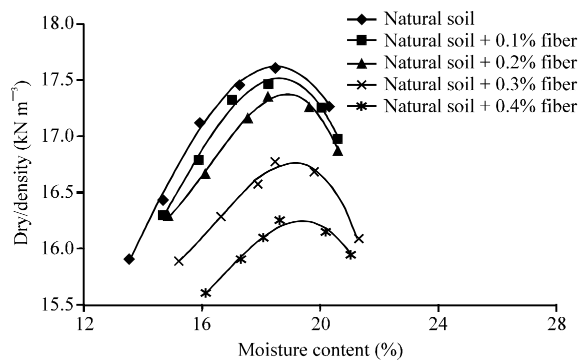

Fig. 8: Results of compaction test on natural soil and mixture of natural soil and polypropylene fiber

Compaction tests: In this study, compaction test by Standard Proctor Method according to ASTM D698 has been carried out. The purpose of performing this test was to investigate compaction characteristics of natural soil (determining optimum moisture content and maximum dry density), soil-lime mixture and also soil-polypropylene fiber mixture. Performing compaction test for soil-polymer mixture was not feasible, because adding of water to soil and polymer mixture and as a consequence its compaction is impossible.

Compaction tests on natural soil natural soil and lime mixture was performed at 2, 4 and 6% of lime and for mixture of natural soil and polypropylene fiber was done at percents 0.1, 0.2, 0.3 and 0.4%. Regarding to obtained results for natural soil, optimum moisture content and maximum dry density were 18.5% and 17.6 kN m^{-3}, respectively. Results of compaction test on natural soil and mixture of natural soil and lime are shown as compaction curves in Fig. 7.

Decrease of maximum dry density by adding lime to the soil could be as a result of higher density of soil particles (Gs = 2.73) with respect to lime particles (GL = 2.23). Increase of optimum moisture content could be the result of hydration and pozolaneous reaction between lime and soil and also hydrophilic characteristic of lime, as by adding more lime to soil optimum moisture will increase. These results confirmed the obtained results of Al-Amoudi (1994).

Results of compaction test on natural soil and mixture of natural soil and polypropylene fiber at 0.1, 0.2, 0.3 and 0.4 % shown as compaction curve in Fig. 8.

According to the compaction test results, one could observe that adding lime and polypropylene fiber to studied soil lead to decrease of maximum dry density and increase of optimum moisture content that is negligible in reinforced samples with polypropylene fiber. The obtained results from the Fig. 8, is in a good agreement with the past research works (Cai *et al*., 2006).

Swelling potential tests: Swelling potential tests has been carried out according to ASTM D4546 standard. The aim of this test was to obtain the swelling parameters (free swelling and swelling pressure) that is consistent with the final purpose of this study, in which, is investigating volume change parameters of saline soil and the effect of stabilization on them. Swelling potential tests comprise of

Table 5: Swelling potential test results for undisturbed and disturbed samples

Properties of soil	Free swelling (mm)	Free swelling (%)	Free normalized swelling with respect to disturbed sample (%)	Swelling pressure (kPa)	Swelling pressure with respect to disturbed sample (%)
Undisturbed sample	0.12	0.80	11.32	39.23	21.98
Disturbed sample (filed density and moisture content)	1.78	9.22	130.41	166.71	93.41
Disturbed sample (MMD and OMC)	1.35	7.07	100.0	178.48	100.0

Table 6: Results of swelling potential test for stabilized samples with lime

Properties of soil	Free swelling (%)	Free normalized swelling with respect to disturbed sample* (%)	Swelling pressure (kPa)	Swelling pressure with respect to disturbed sample* (%)
Stabilized sample with 2% lime by one week curing time	1.54	21.74	58.84	32.97
Stabilized sample with 4% lime by one week curing time	1.21	17.12	52.49	29.41
Stabilized sample with 6% lime by one week curing time	0.88	12.51	39.80	22.30
Stabilized sample with 2% lime by two week curing time	1.36	19.21	53.53	29.99
Stabilized sample with 4% lime by two week curing time	1.00	14.17	50.76	28.44
Stabilized sample with 6% lime by two week curing time	0.82	11.54	38.65	21.66
Stabilized sample with 2% lime by three week curing time	1.18	16.69	52.26	29.28
Stabilized sample with 4% lime by three week curing time	0.80	11.32	47.30	26.50
Stabilized sample with 6% lime by three week curing time	0.73	10.23	35.19	19.72
Stabilized sample with 2% lime by four week curing time	0.92	13.07	47.30	26.50
Stabilized sample with 4% lime by four week curing time	0.58	8.20	45.00	25.21
Stabilized sample with 6% lime by four week curing time	0.49	6.93	26.54	14.87

*Reconstructed sample with natural soil with maximum dry density and optimum moisture content

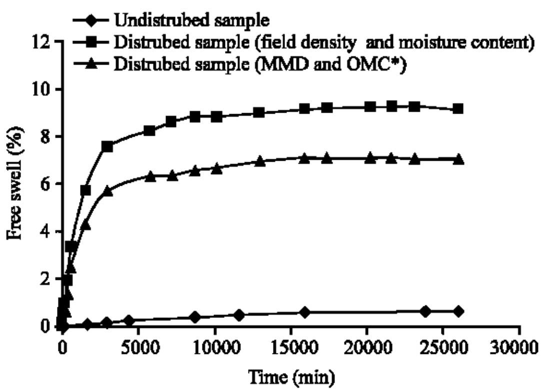

Fig. 9: Swelling curve of soil with respect to time for undisturbed and disturbed samples. *MDD: Maximum dry density and OMC: Optimum moisture content

two parts, the first part is free swelling of sample under negligible surcharge pressure (about 1 kPa) and the second pert is determination of swelling pressure.

Swelling potential tests on natural soil: Figure 9 shows the free swelling curve of soil with respect to time for three samples including; undisturbed, site condition reconstructed disturbed and reconstructed disturbed with maximum dry density and optimum moisture content. As shown in this Fig. 9 effect of disturbance on swelling is clear. According to obtained results of swelling tests on aforementioned soil, one could conclude that main cause of swelling is disturbance and destruction of initial composition and structure of the soil. Considering the fact that in common civil engineering projects such as bridges, subways and canals that disturbance of soil is inevitable (this study was around location of a bridge), for reducing excessive swelling, different methods for soil improvement are used.

After final swelling of sample, swelling pressure of undisturbed and disturbed samples was determined with odometer apparatus. Free swelling test results and swelling pressure determination of mentioned samples have been shown in Table 5.

Swelling potential tests on stabilized samples with lime: In order to show the influence of stabilization with lime on swelling characteristics of soil, swelling potential tests on stabilized samples with 2, 4 and 6% of lime content and curing time of 7, 14, 21 and 28 days were conducted. Free swelling test results and result of swelling pressure determination on stabilized samples with lime are given in Table 6.

By analyzing obtained results of swelling potential of stabilized samples with lime, one could conclude that stabilization of mentioned soil with lime is efficient and reduces considerably the free swelling and the swelling pressure compared to the natural soil. Thus, it could be concluded that stabilization of soil with lime is favorable. Fig. 10 and 11 show the effect of lime on free swelling and swelling pressure with respect to the lime content and different curing times. Similar investigation have done by Raymond and Ouhadi (2007) and confirmed the obtained results in this study.

Swelling potential tests on stabilized samples with polymer: In order to understand the effect of stabilization on swelling characteristic of studied soil, swelling potential tests on stabilized samples with 4, 5, 7 and 9% of polymer and also curing time of 1, 3 and 7 days were conducted. Results of the free swelling test and the swelling pressure determination test on stabilized samples with polymer are shown in Table 7. With analyzing obtained results in free swelling test and swelling pressure determination tests on stabilized samples with aforementioned condition, one could conclude that stabilization of studied soil with polymer is effective and considerably reduces free swelling of soil compared to non-stabilized state. As observed in earlier, adding polymer to saline soil leads to a decrease the free swelling significantly that is very favorable. The cause of increasing the swelling pressure of the stabilized soil with polymer in spite of reducing the free swelling is the fact that stabilized soil after presence of water and beginning of free swelling during chemical reactions that take place between soil and polymer becomes more rigid and for returning to initial state (reach zero free swelling) requires more exerting pressure. Figure 12 shows the effect of polymer on free swelling pressure of saline studied soil.

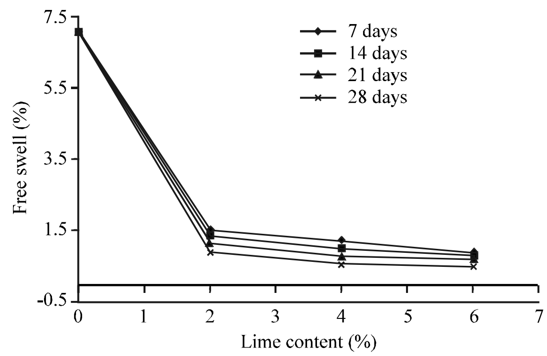

Fig. 10: The effect of lime on free swelling of saline soil

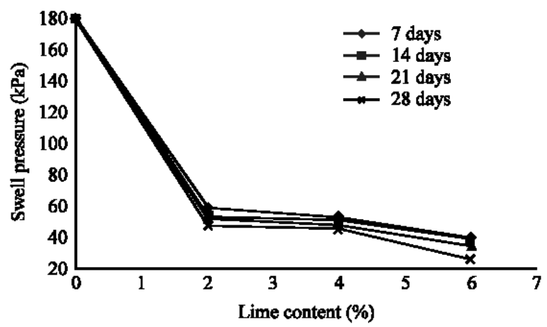

Fig. 11: The effect of lime on swelling pressure of saline soil

Swelling potential tests on reinforced samples with polypropylene fiber: In order to understand the effect of reinforcement with polypropylene fiber on swelling behaviour of studied soil, swelling potential tests were conducted on reinforced samples with 0.1, 0.2, 0.3 and 0.4% of polypropylene fiber. Obtained results are shown in Table 8.

From the results of Table 8, one could conclude that reinforcement of soil with polypropylene fiber is effective and reduce free swelling and swelling pressure of soil with respect to the non-stabilized soil state. Summarizing results of the free swelling tests on reinforced samples with polypropylene fiber, one could depict free swelling percent with respect to percent of polypropylene fiber of

Table 7: Results of swelling potential test on stabilized samples with polymer

Properties of soil	Free swelling (%)	Free normalized swelling with respect to disturbed sample* (%)	Swelling pressure (kPa)	Swelling pressure with respect to disturbed sample* (%)
Stabilized sample with 4% polymer by one day curing time	1.11	15.63	124.55	69.78
Stabilized sample with 5% polymer by one day curing time	1.00	14.14	100.03	56.04
Stabilized sample with 7% polymer by one day curing time	1.21	17.17	168.68	94.51
Stabilized sample with 9% polymer by one day curing time	1.26	17.87	200.06	112.09
Stabilized sample with 4% polymer by three days curing time	1.35	19.13	174.56	97.80
Stabilized sample with 5% polymer by three days curing time	1.17	16.57	150.04	84.07
Stabilized sample with 7% polymer by three days curing time	1.42	20.15	174.56	97.80
Stabilized sample with 9% polymer by three days curing time	1.20	16.92	200.06	112.09
Stabilized sample with 4% polymer by seven days curing time	1.08	15.03	150.04	84.07
Stabilized sample with 5% polymer by seven days curing time	0.99	13.96	124.55	69.78
Stabilized sample with 7% polymer by seven days curing time	1.03	14.51	161.81	90.66
Stabilized sample with 9% polymer by seven days curing time	0.92	13.03	174.56	97.80

*Reconstructed sample with natural soil with maximum dry density and optimum moisture content

Table 8: Results of swelling potential tests on reinforced samples with polypropylene fiber

Polypropylene fiber content (%)	Free swelling (%)	Free normalized swelling with respect to disturbed sample* (%)	Swelling pressure (kPa)	Swelling pressure with respect to disturbed sample* (%)
0.1	2.74	38.76	50.01	28.02
0.2	1.64	23.20	33.34	18.58
0.3	2.21	31.26	44.13	24.73
0.4	3.24	45.83	49.03	27.47

*Reconstructed sample with natural soil with maximum dry density and optimum moisture content

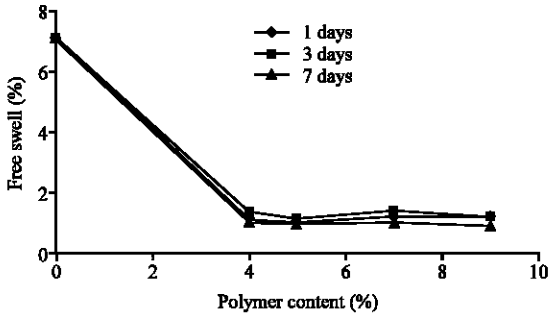

Fig. 12: The effect of polymer on free swelling pressure of saline studied soil

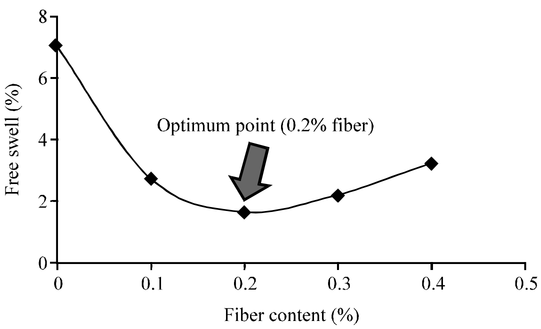

Fig. 13: Free swelling percent with respect to amount of polypropylene fiber for reinforced samples with polypropylene fiber

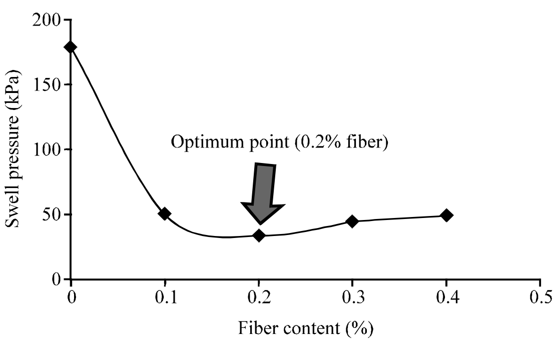

Fig. 14: Swelling pressure curve with respect to polypropylene fiber

reinforced samples that is shown in Fig. 13. Past research works confirmed the obtained results (Tang *et al*., 2007).

As discussed earlier, besides reducing the free swelling, the swelling pressure of reinforced sample has been reduced. Swelling pressure curve with respect to amount of polypropylene fiber has been shown in Fig. 14.

Consolidation test results: Consolidation tests according to ASTM D2435 were carried out on saturated specimens.

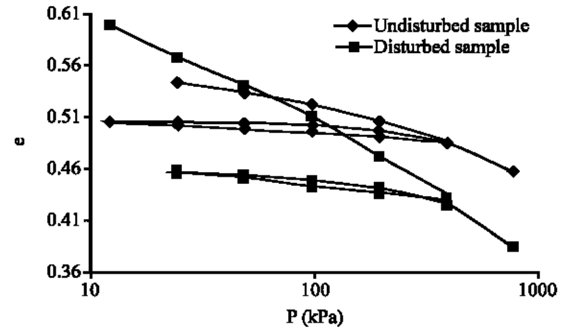

Fig. 15: Effect of disturbance in e-log p curve

The main purpose of this test was to obtain consolidation parameters of soil (consolidation settlement, compressive index, consolidation coefficient). In this study samples with 75 mm diameter and height of 20 mm were used.

Results of consolidation tests consist of three parts:

- Results of consolidation tests on disturbed and undisturbed samples for the natural soil
- Results of consolidation tests on stabilized samples using lime
- Results of consolidation tests on reinforced samples using polypropylene fiber

It should be noted that consolidation test of stabilized samples with polymer was impossible because of setting phenomenon of hardened polymer.

For determination of consolidation coefficient Taylor's square root of time method was used. Considering the fact that consolidation parameters such as consolidation coefficient (C_v), volume change coefficient (m_v), compressibility factor $(a)_v$ and permeability factor (K) varies during consolidation test and also at different pressures, the reported values in this study are average of obtained values at stress range of 100-200 kPa. This range has been selected with regard to typical exerting vehicle loads over subsoil. For determination of over-consolidation pressure (P_c) Casagrande depiction method (1936) on pressure- void ratio curve was used.

Consolidation tests on natural soil: Investigations on consolidation parameters of saline soil in three different states (undisturbed, reconstructed disturbed sample with *in situ* moisture content and density and reconstructed disturbed sample with maximum dry density and optimum moisture content) have been carried out using standard compaction test. To observe the effect of disturbance, pressure-void ratio curve for disturbed and undisturbed specimens are shown in Fig. 15. As could be observed

Table 9: Consolidation parameters of natural soil

Consolidation parameters	Symbol	Undisturbed sample	Disturbed sample (filed density and moisture content)	Disturbed sample (MMD and OMC)
Overconsolidation pressure (kPa)	P_c	183	110	168
Compression index	c_c	0.091	0.134	0.182
Swell index	c_s	0.012	0.023	0.013
Recompression index	c_r	0.020	0.045	0.031
Coefficient of Consolidation (cm² sec⁻¹)	c_V	4.48e-4	6.43e-4	6.06e-4
Coefficient of volume change (cm² kg⁻¹)	m_V	0.013	0.033	0.024
Coefficient of compressibility (cm² kg⁻¹)	a_V	0.020	0.053	0.039
Coefficient of permeability (cm sec⁻¹)	k	0.58e-8	2.1e-8	1.4e-8
Young's modulus (kg cm⁻²)	E	100.79	37.46	51.63

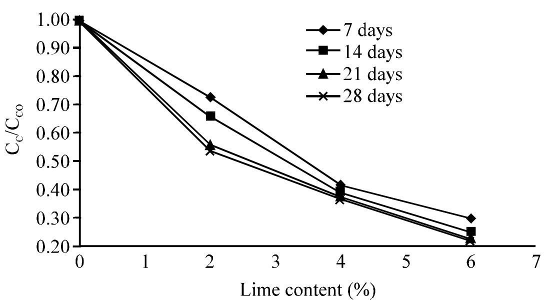

Fig. 16: Effect of lime on compressive index in the normalized form. C_{CO} = 0.182

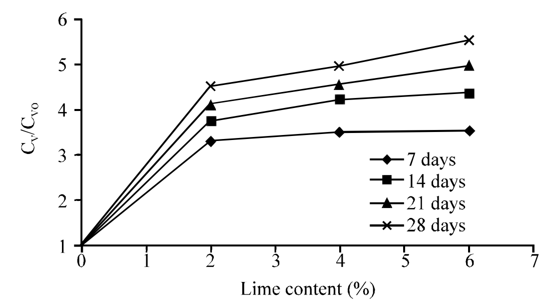

Fig. 17: Effect of lime on consolidation coefficient in the normalized form. C_{VO} = 6.06E-4

from Fig. 15 disturbance leads to an increase in consolidation settlement and also increase in slope of void ratio-pressure curve. Consolidation parameters obtained by consolidation test for three states are presented in Table 9. From results of Table 9, one could conclude that due to disturbance, the consolidation coefficient has been increased and elasticity modulus and over-consolidation pressure have been decreased. This could be explained with regard to the fact that disturbance phenomenon could lead to a higher void ratios because of destruction of initial composition of soil structure and consequently larger consolidation settlements encountered.

Consolidation tests on stabilized samples with lime: For conducting consolidation test on stabilized samples with lime, samples with optimum moisture content and maximum dry density obtained by results of standard compaction test, constructed on saline soil with 2, 4 and 6% of lime content. Thereafter, for curing time (7, 14, 21 and 28 days), samples were kept in plastic membranes and after that set into odometer test apparatus and after saturation and free swelling went under consolidation test. For studying the effect of lime on compressive index (C_c), Fig. 16 shows compressive index with respect to amount of added lime content that has been normalized relative to compressive index of natural soil. As it is obvious in this Fig. 16 addition of lime to studied saline soil leads to decrease in C_c. This decrease is a result of lime setting with soil and strength of sample against settlement that this strength will be more with increase of lime content and also curing time and consequently, slope of initial loading curve reduced which means for a specified increase in pressure, lower reduction of void ratio will be achieved, compared to the natural soil. The obtained results have a an excellent agreement with the results of Al-Zoubi (2008).

To observe the effect of lime on consolidation coefficient (C_c), Fig. 17 shows consolidation coefficients with respect to the added lime content that has been normalized relative to consolidation coefficient of natural soil. As it is obvious in this Fig. 17 addition of lime to studied saline soil leads to an increase in the consolidation coefficient that its growth rate is increasing with adding of lime for different curing times.

Consolidation tests on reinforced samples using polypropylene fiber: For conducting consolidation test on reinforced samples with polypropylene fiber, samples with optimum moisture content and maximum dry density, samples with 0.1, 0.2, 0.3 and 0.4% of polypropylene fiber were made. After that samples placed into odometer apparatus and after saturation and free swelling went under consolidation test.

Figure 18 shows compressive index with respect to amount of polypropylene fiber that has been normalized relative to the compressive index of natural saline soil.

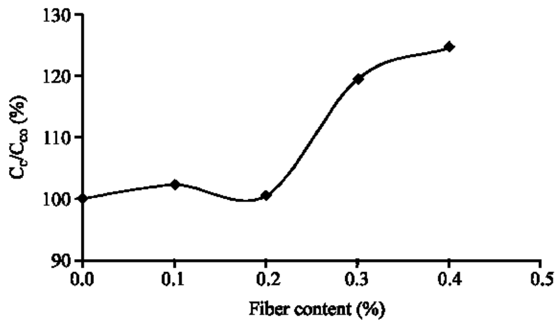

Fig. 18: Effect of polypropylene fiber on soil compression index in the normalized form. C_{CO} = 0.182

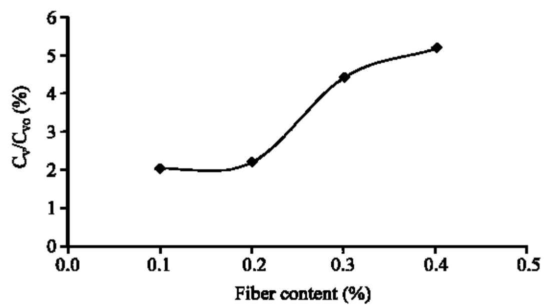

Fig. 19: The effect of polypropylene fiber on soil consolidation coefficient as normalized form. C_{VO} = 6.06E-4

As could be observed form Fig. 18, adding polypropylene fiber to saline studied soil leads to an increase of compressive index that its rate with increase of polypropylene fiber will be negligible till reach 0.2% of polypropylene fiber content, afterwards compressive index increased significantly. These increases are due to enhancement of void ratio and as a consequence lead to increase in consolidation settlement. Therefore, it is expected that slope of initial loading curve will be increased. With regard to this curve, one could observed that compressive index of soil with adding 0.1, 0.2, 0.3 and 0.4% of polypropylene fiber has been increased 1.23, 1.06, 1.19 and 1.24 time with respect to non-stabilized state, respectively. This fact indicates that more settlement of soil will be achieved with adding polypropylene fiber, therefore it makes an unfavorable geotechnical condition. Also, these results have a good agreement with the Tang *et al.* (2007).

To compare the effect of polypropylene fiber on consolidation coefficient, Fig. 19 shows normalized consolidation coefficient curve with respect to the content of polypropylene fiber. As could be observed form Fig. 19 adding polypropylene fiber to saline studied soil leads to increase of consolidation coefficient that rate of growth increase with more addition of polypropylene fiber.

CONCLUSIONS

In this study results of experimental investigations on volume change behaviour of a saline soil as disturbed, undisturbed and stabilized with lime and polymer and also reinforced with polypropylene fiber have been presented. According to conducted tests the following conclusions could be drawn:

- According to the results of swelling tests, it is observed that the main cause of swelling of the soil is disturbance and destruction of the initial composition of soil structure. Disturbance cause more consolidation settlement and also will increase slope of void ratio-pressure curve. Despite higher densities of reconstructed samples with regard to the condition of mentioned site, in initial loading condition, showed more consolidation settlement compared to the constructed samples with optimum moisture content and maximum dry density
- Disturbance also leads to a increase in consolidation coefficient
- Adding lime, polymer and polypropylene fiber to soil cause a decrease in liquid limit of the soil, but this decrease was more by adding lime and polymer in comparison with polypropylene fiber
- Comparison between swelling parameters (free swelling and swelling pressure) of stabilized specimens with polymer and lime and reinforced specimens with polypropylene fiber showed that all of them decrease free swelling, nonetheless about swelling pressure, 9% of polymer leads to an increase and in other cases lead to decrease in swelling pressure. This fact is a disadvantage of stabilization with polymer
- Comparisons between setting time of stabilized samples with lime and polymer showed that setting time of polymer is very fast relative to lime
- Comparisons between consolidation parameters of stabilized samples with lime and polymer and reinforced samples with polypropylene fiber showed that consolidation settlement increased in stabilized samples with polypropylene fiber. In contrast, in stabilized samples with lime consolidation settlement, decreased. Both of the stabilizers and reinforcement agent, increased consolidation coefficient. Adding lime to saline soil, increase elasticity modulus of soil, but the other cases lead to decrease in it. This fact is one disadvantages of stabilization with polypropylene fiber

Considering all conditions and results and interpretations, it can be concluded that using lime to stabilize the saline clayey soil is more advantageous rather than using polymer and polypropylene fiber. It is also appear that although lime is a traditional stabilizer, nevertheless is an economic stabilizer for most of plans and using polymer due to its rapid setting of is suggested only in special plans.

REFERENCES

Abdi, M. and A. Ibrahimi, 2003. Effect of length and amount of polypropylene fiber on mechanical properties of Kaolinite. M.Sc. Thesis, Khajeh Nasiraddin Tusi, Tehran, Iran.

Al-Amoudi, O.S.B., 1994. Chemical stabilization of sabkha soils at high moisture contents. Eng. Geol., 36: 279-291.

Al-Rawas, A.A., A.W. Hago and H. Al-Sarmi, 2005. Effect of lime, cement and saroj on the swelling potential of an expansive soil from Oman. Building Environ., 40: 681-687.

Al-Zoubi, M.S., 2008. Swell characteristics of natural and treated compacted clays. EJGE, 13: 1-18.

Amu, O.O., J.B. Adeyeri, E.W. Oduma and O.A. Fayokun, 2008. Stabilization characteristics of lime on palm kernel blended lateritic soil. Trends Applied Sci. Res., 3: 182-188.

Ashayeri, Y. and Shahabadin, 2004. Experimental study of volume change behaviour and swelling pressure of grinded clayey soil. Proceedings of the 1st Civil Engineer National Congress, Sharif Technology University, Sept. 11-13, Sharif University of Technology, Tehran, Iran, pp: 631-639.

Cai, Y., B. Shi, C.W.W. Ng and C. Tang, 2006. Effect of polypropylene fibre and lime admixture on engineering properties of clayey soil. Eng. Geol., 87: 230-240.

Faluyi, S.O. and O.O. Amu, 2005. Effects of lime stabilization on the ph values of lateritic soils in ado-ekiti, Nigeria. J. Applied Sci., 5: 192-194.

Fang, H.Y., 1991. Foundation Engineering Handbook. The Chapman and Hall, New York.

Foncea, C., P. Acevedo and R. Olguin, 2005. Geotechnical characterization of saline soils. Proc. 16th Int. Conf. Soil Mechanics Geotechnical Eng., 2: 503-506.

Kehl, M., 2006. Saline soils of IRAN with examples from the alluvial plain of Korbal, Zagros Mountains. Proceedings of the International Conference on Soil and Desertification-Integrated Research for the Sustainable Management of Soils in Drylands, May 5-6, Hamburg, German, Japan, pp: 1731-1734.

Raymond, N.Y. and V.R. Ouhadi, 2007. Experimental study on instability of bases on natural and lime/cement-stabilized clayey soils. Applied Clay Sci., 35: 238-249.

Tang, C., B. Shi, W. Gao, F. Chen and Y. Cai, 2007. Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil. Geotextiles Geomembranes, 25: 194-202.