Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2013, 5(11):787-794

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Study of thermal conductivity and salt-heaving law of coast chlorine saline soil under multiple freezing and thawing cycles

***Jin Wei and Qinwen Du**

School of Highway, Chang' an University, Xi' an, Shaanxi, China

---

ABSTRACT

In order to further study the thermal conductivity and salt-heaving property of coast chlorine saline soil, the laboratory simulation test research was carried out under the conditions of different initial water contents, salt contents, freezing and thawing cycles and loads. The test results show that the thermal conductivity coefficient increases with the increase of sodium chorine salt content under above zero temperature, and decreases with the increase of salt content under subzero temperature. The thermal conductivity coefficient decreases with the rise of temperature in the subzero temperature section, and increases with the rise of temperature in the above zero temperature section. The temperature-fall range of 5°C ~ −10°C is the rapid increase period of salt- heaving quantity. Under freezing and thawing cycle condition, the residual salt-heaving quantity is produced in the saline soil and it shows obvious salt-heaving accumulation. The accumulation weakens with the increase of the freezing and thawing cycle times. The load has obvious inhibition and delay effect on the salt-heaving quantity and the initial expansion temperature.

Key words: Road engineering, Chlorine saline soil, Freezing and thawing cycle load, Thermal conductivity, Salt-heaving

---

INTRODUCTION

China is one of the countries where coast chlorine saline soil is widely distributed. It is mainly distributed in the coastal plains of the provinces and cities in the north of Yangtze River such as Jiangsu, Shandong, Hebei, Tianjing, Liaoning and so on, and sporadically distributed littoral areas in the south of Yangtze River. The coastal region is influenced by seawater immersion and coast regression, so the groundwater level and the mineralization degree of the water are high. By evaporation and capillary action, the salt of the water is gathered on the ground surface or the soil which is located in a not very deep distance under the ground surface, and then the coast chlorine saline soil is formed. The northern subregion is chloride saline soil, with 2%~8% saltness[1]. The special geographic location, natural environment and weather conditions (large amount of precipitation, much surface water, high underground water level) of coastal area result in specific engineering characteristic presented by the saline soil in the area (salt-heaving, melt-sinking and corrosivity). If not properly disposed, it will cause many diseases. So far, people have comprehensively known the property of sulfate saline oil, and the relatively thorough salt-heaving theory of saline soil is gradually formed[2-5,9,10]. However, there is little research about the coast saline soil for which chlorine salt is the main component. Therefore, this article takes the typical chlorine saline soil in the west coast of Bohai Sea as the research object, and research the heat conduction and salt-heaving property and law by laboratory simulation test.

EXPERIMENTAL SECTION

2.1 Basic property of saline soil
The mean annual precipitation in the west coast of Bohai Sea is 560mm, and the rainfall changes greatly with the seasonal variation. The rainfall in winter and spring is little, and it is concentrated in summer. The annual average temperature is 12.3°C, with 40.9°C maximum high temperature and -18.3°C minimum low temperature. Most areas belong to slight desalting zone of underground water. The underground water level is relatively high, with up to 10—35g/L mineralization degree and high saltness. The high mineralization and saltness make the salt gather on the ground surface constantly by capillary water action during surface water evaporation. Some forms salt rust or pellicular salt on the ground surface and saline soil layer to certain extent. In order to have a detailed understanding of the developmental situation and salinity degree of saline soil in the research area, we take the representative samples for saline soil (soluble salt) test. See the result in Table.1.

Table 1. Ion content of the test saline soil

Soil Sample No.	Content of Ions （%）							Total Salt Content（%）	Cl^-/SO_4^{2-}
	CO_3^{2-}	$HC0_3^-$	Cl^-	SO_4^{2-}	Ca_3^{2-}	Mg^{2-}	K^++Na^+		
1	0.0015	0.0244	1.2230	0.1513	0.016	0.0274	0.8058	2.25	8.1
2	0.003	0.0336	1.1344	0.2402	0.0301	0.0547	0.7276	2.22	4.7
3	0.0045	0.0381	1.1344	0.1201	0.01	0.0365	0.7305	2.07	9.4
4	0.0033	0.0357	1.1284	0.2282	0.0341	0.0525	0.7346	2.22	4.9

The table shows that the Cl^-/SO_4^{2-} of the saline soil are all over 2. As per the classification of saline soil in Test Methods of Soils for Highway Engineering (JTGE40—2007)[11], it is typical chlorine saline soil. The soluble salt content of saline soil is between 1.5% ~ 5%. According to the salinization degree, it belongs to medium saline soil.

2.2 Thermal conductivity coefficient test
Thermal conductivity is an important thermal physical property for saline soil. The thermal conductivity research of saline soil has great significance for analyzing the hydrothermal condition, geothermal condition, and migration process of salinity and water during freezing and thawing process of different saline soil[12].

2.3 Test principle
The methods for testing the thermal conductivity coefficient are stable state method and unstable state method. The heat-pole method of unstable state method is used for this test. The basic principle of heat-pole method is that put a resistance wire (i.e. so-called “heat pole”) in the samples with homogeneous quality and temperature. Once the heat pole releases heat under the action of constant power (current), the temperature of heat pole and nearby samples will rise. The thermal conductivity coefficient of the samples can be determined as per the relationship that the temperature changes over time.

The definition of thermal conductivity coefficient[6] is that: the amount of heat is produced by passing through per unit area of soil within per unit time under per unit temperature gradient ($W/ m^{-1} \cdot K^{-1}$).

2.4 Test program
The heat-pole method of unstable state method is used for testing the thermal conductivity coefficient of the saline soil. The test instrument is TC222 value thermal conduction device.

The operating steps are as follows:
(1) Prepare the sample: Prepare the water content per the requirements. After preparation, tightly cover the soil samples for 2~4 h. Put the testing soil samples in two sample boxes with sizes of 20 cm ×12 cm ×5 cm per the required dry density.
(2) Switch on the main power supply, and warm up the instrument for 30~60 min.
(3) The zero temperature bottle must be filled with ice water mixture (1.75:1).
(4) Install the testing samples and switch on all relevant connecting wires.
(5) Adjust the pointer of the thermometer to aligning it at the zero position.
(6) Test the temperature of the samples, and adjust the set temperature to the sample temperature.

(7) Choose the optimum current value for tested samples.
(8) After the temperature pointer goes back to zero position, start testing the thermal conductivity coefficient of the samples.
(9) After finishing the melted soil test, Put it under the subzero temperature for freezing. After freezing for 8~12 h, take it out and repeat above steps to test the thermal conductivity coefficient of the frozen soil under different subzero temperature conditions.

2.5 Testing soil samples

Choose natural chlorine saline soil with different saltness (2%, 3%, 4%, 5%)as testing soil samples. The dry density and water content are 1.92 g/ cm3 and 15.6% respectively (standard heavy compaction test). The soil samples are silty clay.

RESULTS AND DISCUSSION

3.1 Analysis of the test results

The thermal conductivity coefficient laboratory test for the natural chlorine saline soil with three kinds of saltness is carried out under above test condition. The test results are shown on figure1~2.

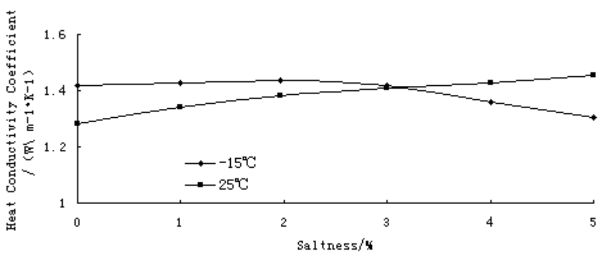

Figure 1. Curves of thermal conductivity coefficient vs. salt content

Figure1 shows the test results of thermal conductivity coefficient for saline soil with different saltness under the temperature of 25°C and -15°C. From Fig.1, the thermal conductivity coefficient of saline soil increases with the increase of saltness under the temperature of 25°C. The analysis is as follows: Under the same condition, the thermal conductivity coefficient of saline solution in the soil is more than that in the soil particles. When the temperature is 25°C, the solubility of sodium chloride is relatively high, and the solution (saline solution) content in the soil increases with the increase of saltness, which make the thermal conductivity coefficient of soil increase gradually. When the temperature is -15°C, the thermal conductivity coefficient of saline soil decreases with the increase of saltness. This is because most sodium chloride in the soil combines with water molecules and separates the crystal out, which makes the saline solution reduce greatly and the thermal conductivity coefficient reduces therewith.

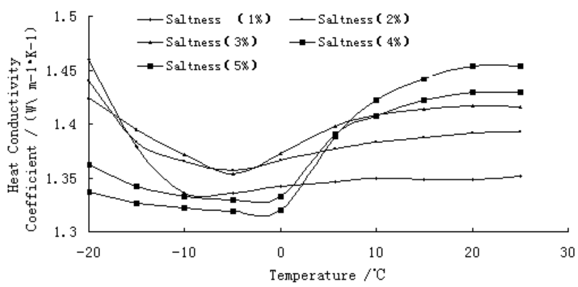

Figure 2. Curves of thermal conductivity coefficient vs. temperature

Figure2 is the curve where the thermal conductivity coefficient of saline soil with different contents changes with temperature. It can be seen from Fig. 2 that: 1) In the subzero temperature section (0 ~ - 20°C), the thermal conductivity coefficient of saline soil decreases with the rise of temperature. This is because with the rise of temperature, the content of unfrozen water in the soil increases gradually, and the content of ice decreases gradually, which make the thermal conductivity coefficient decreases gradually. 2) In the above zero temperature section

(0 ~ 25°C), the thermal conductivity coefficient of saline soil slightly increases with the rise of temperature. This is because the solubility of salt increases with the rise of temperature. The separated sodium sulfate crystal turns into sodium sulfate solution, and the saline solution in the soil increases gradually, which make the thermal conductivity coefficient increase gradually.

3.2 Test program

Apply the laboratory simulation test, simulating the temperature-fall process in the winter and the temperature-rise in the spring. The temperature-fall process (top temperature of the sample/bottom temperature of the sample)is

20°C /20°C →5°C /5°C →0°C /5°C →－5°C /0°C →－10°C /0°C →－15°C /－5°C →－20°C /－5°C.

Single temperature-fall gradient lasts 8h, totally 48h. The temperature-rise process is carried out in reverse order. In order to make the boundary condition of the sample resemble the natural condition, the thermal insulation material is wrapped around the sample tube, to prevent the sample from heat exchanging with the surrounding. Mould the soil material which is prepared per the optimum water content under the temperature of 20°C, that is, put the prepared soil material into the sample tube which is 40cm high with 11.6cm inner diameter in five times, and compact it respectively to reach the maximum dry density. Install the dial indicator vertically on the top of the top cold head, to measure the salt-heaving quantity of soil sample. Load weight and install counter-force device on the top cold head, to simulate the load of the soil and measure the salt-heaving force. See Figure3 for the test equipment.

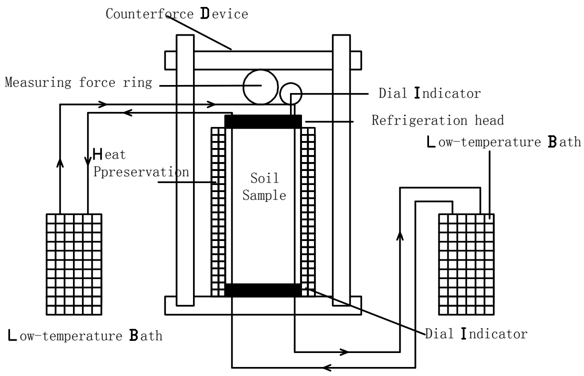

Figure 3. Test devices for salt heaving

3.3 Basic property of the samples

Choose the natural saline soil as the testing soil sample. The maximum dry density and optimum water content obtained by standard heavy compaction are 1.92 g/ cm3 and 15.6% respectively. The variation range of liquid limit of sample soil is between 29.2%~35.5%, the variation range of plastic limit is between 17.6%~20.3%, and the variation range of plastic index is between 11.9%~14.6%. It is silty clay. See table2 for the results of grain size analysis.

Table 2. Grain size distribution of the test saline soil

Quality Percentage of Grain Composition/%					
No.	＞0.074mm	0.074mm~0.01mm	0.01mm~0.005mm	0.005mm~0.002mm	＜0.002mm
1	4.52	42.17	15.78	17.9	19.63
2	5.17	42.79	15.32	18.12	18.6
3	5.25	42.32	16.03	18.13	18.27

3.4 Analysis of the test results

In order to accurately simulate the accumulated salt-heaving property of natural saline soil under seasonal temperature change, the salt-heaving quantity law of samples with different salt is obtained by accomplishing four temperature-falls and one temperature-rise in the test. See figure4~6 respectively.

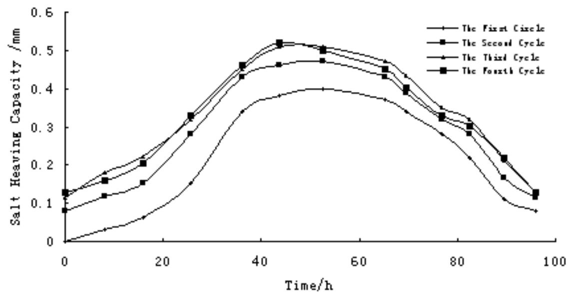

Figure 4. Amount of salt expansion of 2% salt content sample

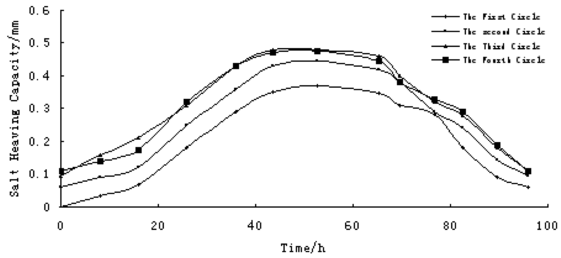

Figure 5. Amount of salt expansion of 3% salt content sample

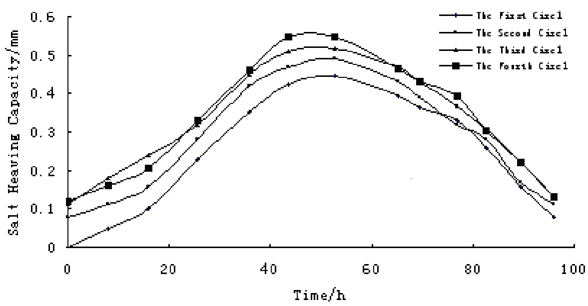

Figure 6. Amount of salt expansion of 4% salt content sample

The figures show that the salt-heaving quantity of soil samples increases with the decrease of temperature. When the temperature reaches the minimum value, the salt-heaving quantity achieves peak value and it decreases gradually with the rise of temperature. When the temperature rises to 20°C, the salt-heaving quantity does not fall back to zero, that is, the residual salt-heaving quantity is caused. In the next freezing and thawing cycle, the salt-heaving quantity continues increasing based on the salt-heaving quantity of the first cycle, which shows obvious salt-heaving accumulation. The reasons for residual salt-heaving quantity and accumulated salt-heaving quantity are that the chlorine salt in the soil crystallizes and increases in volume during temperature-fall. The crystals apply relatively large expansion force on soil particles[7] which make the soil particles move and misplace, and then the soil volume expands, which is called salt-heaving. During temperature-rise, the chlorine salt crystals dissolve gradually, and the expansion force applied on the soil particles decreases and even disappears. The spatial position of the soil particles will rearrange. Most of the small particles fall back into the gap. Some particles with relatively big grain diameter reach new force balance during interaction with other particles, and do not recover to the original stress state. Therefore, the soil sample presents the residual salt-heaving quantity after temperature-rise. In the next freezing and thawing cycle, the soil particles produce further salt-heaving in the new stress state and position, that is, the accumulative effect of salt-heaving is produced under the freezing and thawing cycle. After two freezing and thawing cycles are completed, the soil turns soft, thus the salt-heaving quantity consumed in the interior of the soil increases during temperature-fall period[8]. The salt-heaving accumulative effect of soil weakens. Finally, the total salt-heaving quantity tends to stable value, and the soil particles reach relatively stable balance state. It means that the accumulative effect does not have non-infinite superposition property.

See table3 for the maximum salt-heaving of the saline soil with different salt contents. See figure7 for the relationship between salt-heaving rate and freezing and thawing cycle.

Table 3. Salt expansion ratio of different salt content sample

Freezing and Thawing Cycle/time	Saltness 2%		Saltness 3%		Saltness 4%	
	Maximum Salt-heaving Quantity/mm m	Salt-heaving Rate /%	Maximum Salt-heaving Quantity /mm	Salt-heaving Rate /%	Maximum Salt-heaving Quantity /mm	Salt-heaving Rate/%
1	0.37	0.092	0.40	0.100	0.45	0.112
2	0.45	0.111	0.47	0.118	0.49	0.123
3	0.48	0.120	0.51	0.128	0.52	0.123
4	0.48	0.119	0.50	0.125	0.55	0.137

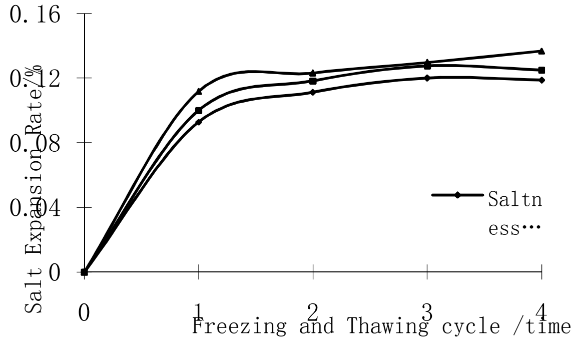

Figure 7. Curves of salt expansion ratio vs. freezing and thawing cycles

As shown on figure7, the relationship between the salt-heaving rate of saline soil with different salt contents and freezing and thawing cycle conforms to the change law of cubic parabola. Therefore, parabola is used for regression analysis.

The regression equation of salt-heaving rate of saline soil with 2% salt content and the freezing and thawing cycle:

$$\left.\begin{aligned} Y = 0.0054x^3 - 0.0463x^2 + 0.129x + 0.0009 \\ R^2 = 0.9942 \end{aligned}\right\} \quad (1)$$

The regression equation of salt-heaving rate of saline soil with 3% salt content and the freezing and thawing cycle:

$$\left.\begin{aligned} Y = 0.0058x^3 - 0.0503x^2 + 0.1391x + 0.0011 \\ R^2 = 0.9929 \end{aligned}\right\} \quad (2)$$

The regression equation of salt-heaving rate of saline soil with 4% salt content and the freezing and thawing cycle:

$$\left.\begin{aligned} Y = 0.0084x^3 - 0.0657x^2 + 0.1626x + 0.0013 \\ R^2 = 0.9910 \end{aligned}\right\} \quad (3)$$

In the equation, Y is the salt-heaving rate (%), x is the freezing and thawing cycle period (time), and R is the correlation coefficient.

From figure7, the salt-heaving rate of saline soil with different salt content increases with the increase of freezing and thawing cycle times, but it flattens in the third cycle, which shows the non-infinite superposition property of the accumulative effect of salt-heaving.

Apply 50kPa load on the soil by counter-force equipment to simulate the salt-heaving property of soil under load state. See figure 8~9 for the salt-heaving quantity of soil with different salt contents under load and no load state. See table4 for the salt-heaving character contrast.

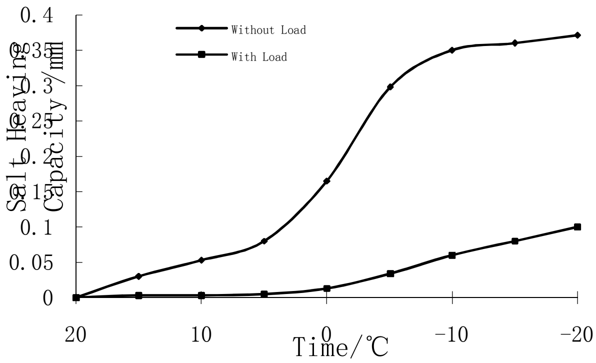

Figure 8. Influence of load to 2% salt content sample

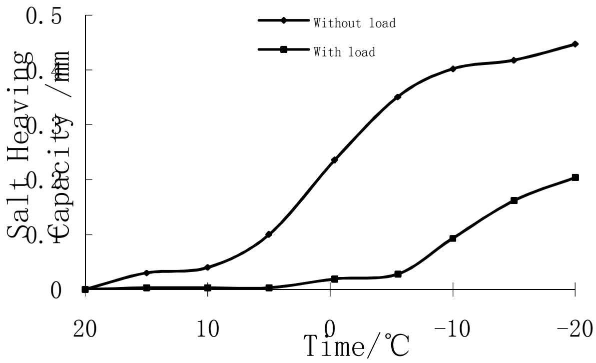

Figure 9. Influence of load to 4% salt content sample

Table 4. Salt-heaving characteristics of samples

Saltness	Temperature of Initial Expansion /°C		Maximum Salt-heaving Quantity /mm		During Severe Salt-heaving /°C	
	With Load	Without Load	With Load	Without Load	With Load	Without Load
2%	5	20	0.10	0.37	0→-20	5→-10
3%	7	20	0.13	0.40	-5→-20	5→-11
4%	6	20	0.21	0.45	-5→-20	5→-11

The figure8~9 show that the salt-heaving quantity with different salt contents has similar law. The distribution curve of salt-heaving quantity can be roughly divided into three stages. The temperature interval of the first stage is 20°C ~5°C, where the salt-heaving quantity increases slowly. The salt-heaving quantity in this stage is about one sixth of the maximum salt-heaving quantity. The temperature interval of the second stage is 5°C ~－10°C, where the salt-heaving quantity increases dramatically. Most salt-heaving quantity is produced in this stage. The temperature interval of the third stage is －10°C ~－20°C, which is the stable phase. The increase of salt-heaving quantity is relatively slow. According to the analysis, firstly, the salinity distribution of the soil is uneven. Since the soil sample is prepared by hand, the water distribution is considered to be even. During slow increase period, some high concentration salinity in the soil begins to crystallize and expand with the decrease of temperature, while most salinity does not begin to separate out. The crystals separated out are filled in the holes of the soil, and have little contribution for the soil volume. Secondly, during dramatical rise period, the further decrease of temperature is the main factor for producing severe salt-heaving. Meanwhile, some space with relatively little salt content in the soil will produce frost heaving because of the freezing of free water, which increases the expansion quantity of the soil. Thirdly, during stable period, most salt contents are crystallized. The salinity of the soil that can produce salt-heaving is quite limited. The salt-heaving quantity has increased to limit value.

It is known by analyzing the table.4 that the influence of load on salt-heaving is reflected on two aspects. The first one is the influence on the salt-heaving. The salt-heaving quantity of soil samples with two different salt contents under load condition decreases by 73% and 54% respectively, which means that the load has obvious inhibition effect on the salt-heaving of saline soil. The second one is the influence on the distribution interval of salt-heaving. It can be seen from the figure that under load condition, the initial expansion temperature of soil is 5°C, which is greatly higher than that under no load condition. It means that the load has obvious delay effect on salt-heaving.

CONCLUSION

For the saline soil with the same water content and dry density, the thermal conductivity coefficient increases with the increase of salt content of sodium chloride under above zero temperature, and the thermal conductivity coefficient decreases with the increase of salt content under subzero temperature. When the salt content is the same, the thermal conductivity coefficient of saline soil decreases with the rise of temperature in the subzero temperature section, and increases with the rise of temperature in the above zero temperature section.

When the cycle of temperature-fall to temperature-rise is finished, the salt-heaving quantity does not go back to zero, and the residual salt-heaving quantity is caused. In the next freezing and thawing cycle, the salt-heaving quantity continues increasing based on the salt-heaving quantity of the first cycle, which shows obvious salt-heaving accumulation. However, the accumulation weakens with the increase of freezing and thawing cycle times.

Under load, the salt-heaving quantity reduces by 73% and 54% respectively, which shows that load has obvious inhibition effect on the salt-heaving of saline soil. The initial expansion temperature of soil is higher than the initial expansion temperature under no load condition, which shows that load has obvious delay effect on salt-heaving.

Acknowledgements
This work was supported by Funding Project of Fundamental Scientific Research Operating Expense Special Fund for Central Universities（2013G1211011）

REFERENCES

[1]F Li, B Li and J Chen. *Journal of Chang'an University*(Natural Science Edition), **2006**, 26(6), 12-14.
[2] ZJ Feng, YL WU and C Cheng. *Chinese Journal of Geotechnical Engineering*, **2010**, 32(9), 1439-1442.
[3] JP G, JH Wu. *Chinese Journal of Geotechnical Engineering*, **1997**, 19(1), 37-42.
[4] WX Bao,YL Xie and XH Yang. *Journal of Engineering Geology*, **2006**, 14(3), 380-385.
[5] SS Zhang, XH Yang and XIE Yongli. *Journal of Chang'an University*(Natural Science Edition), **2009**, 29(1), 20-25.
[6] YS Deng, P He and CL Zhou. *Thermal Conductivity of Saline soils*, **2004**, 26（3）, 319- 22.
[7] NY Li, B Li. *Journal of Xi'an Highway University*, **1989**, **7**(3), 81–90.
[8] SS Gao, YK Shi *Chinese Journal of Geotechnical Engineering*, **1996**, 18(3), 96–99.
[9] YZ Xu. Saline Soil Ground, Architecture and Building Press, Beijing ,(**1993**)
[10] XZ Xu,WANG Jia-cheng and ZHANG Li-xin, Mechanism of Frost Heave and Salt Expansion of Soil, Science Press, Beijing ,(**1995**)
[11] JTG E40-**2007**,Test Methods of Soils for Highway Engineering[S] .
[12] XZ Xu, JC Wang and LX Zhang. Frozen Soil Physics, Science Press, Beijing, (**2001**)