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Analysis of the Engineering Characteristics of Solidified Saline Soil Based on the Microstructure Index Using Response Surface Methodology

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Abstract. Selection of experimental factors such as particle size fractal dimension D_{ps}, particle orientation fractal dimension D_{di}, equivalent diameter D_e , design the experiments using response surface method, Study on the relationship between the mechanical strength index and the optimal microstructure parameters of lime solidified saline soil ,and is verified. The results show that the microstructure of the solidified soil is the best index of particle size fractal dimension D_{ps} 0.8, particle orientation fractal dimension D_{di} 0.93, equivalent diameter D_e 1.75, The mechanical strength of solidified saline soil reached the maximum. The model can be used to analyze and predict the mechanical properties of solidified soil.

Introduction

Saline soil is a special soil of environmental sensitivity, and its engineering properties vary with the changes of water and heat environment. Under the influence of moisture and temperature, soil salt, especially in the phase will happen easily soluble salt crystals and the change of the quantity, make the engineering properties of saline soil is not stable, often appear saline soil area road pavement frost boil, dissolve trap and secondary salinization and other diseases . Inshore saline soil is a kind of shallow sea sediment, it is by the river transportation and jacking and maceration of sea water and ocean currents, tides, waves, determined by such factors as common, mainly distributed in the north of the Yangtze river, Jiangsu, Shandong, Tianjin and other provinces in the coastal plain, the grain size composition is given priority to with fine grained, salt composition is given priority to with sodium chloride, potassium chloride, PH value of 7.5 ~ 7.5, mainly alkaline, usually less than 5% salt content, mainly for the weak or the chlorine saline soil. Because of chlorine saline soil is easy to absorb moisture and softening, most of the project uses lime to cure, in the curing process of soil and solidified materials, physical chemistry, soil structure become dense, mechanical strength has been greatly improved. How to use experimental data processing and statistical methods to establish the relationship between mechanical strength index and microstructure parameters is a problem to be solved at present.

Response surface methodology (RSM) is a kind of statistical method to find the optimal parameters by analyzing the function relationship between the regression equation and the regression equation by using the reasonable experimental design. Design expert is developed by us stat - ease company and widely used experimental design software system, can statistical analysis of test data, fitting curve, establish mathematical model, can also provide two-dimensional contour graphics prediction test results of different factors, can also provide three-dimensional graphics observation response surface, further obtain the optimization of test. In this experiment, the response surface methodology was used to study the relationship between the mechanical strength index and the microstructure of saline soil by the Box-Behnken design of design 8. 0, including unconfined compressive strength, cohesion and internal friction angle.

Test Scheme

Raw Materials

The experimental saline soil is taken from Huanghua city to Huanghua port along the highway, the specific physical properties indicators are shown in table 1. The cured material is calcium oxide powder, the content of Cao + MgO is 70 %.

Test Method

The salt content of the coastal saline soil along the highway is 2 % ~ 4 %, in order to facilitate summary rule, the salt content is 0, 0.3 %, 1.0 %, 3.0 %, 5.0 %, and 8.0 %. Dry salted soil shall be mixed with the optimal water content and salt content, and put into plastic bag for 24 hours, and then add 12 % lime. after mixing and homogenizing, put into the standard curing box curing, the temperature is (20±2) ℃, humidity is more than 90 %, curing to the specified age 7d.

Table 1. Basic physical properties index of soil sample.

Proportion	Consistency index			Heavy duty compaction test		Size of particle size (mm) /%		PH
	ω_L/%	ω_P/%	I_P	ρ_{dmax}/g·cm^{-3}	ω_{op}/%	0.074~0.005	<0.005	
2.70	34.4	20.5	13.9	1.84	15.2	88.61	11.39	8.1

The unconfined compressive strength of a cylinder specimen with a diameter of 50 mm× 50 mm was prepared by a two-way static compaction method. The three - axis UU shear test also adopted the biaxial static compaction method to prepare a cylindrical sample with a diameter of 39.1 mm × 80 mm. Using the german Leo 1530 VP field emission scanning electron microscope (SEM), the SEM pictures of fresh section soil microstructure were collected and scanned and calculated by Leica qwin graphics processing software. The microstructure parameters related to soil were obtained, such as equivalent diameter, oblate degree, filling ratio, area ratio, particle size fractal dimension, particle orientation fractal dimension and so on.

Test Design

There are many parameters of the microstructure parameters of solidified soil, in which the particle size distribution of D_{ps} reflects the fractal dimension of the particle size in the soil, and the particle oriented fractal D_{di} reflects the fractal dimension value of the direction of the particle long axis arrangement, and the equivalent diameter D_e is the equivalent circle diameter equivalent to the particle area. The particle size fractal dimension D_{ps}, particle orientation D_{di}, equivalent diameter D_e as variable A, B, C, according to three variables three levels, using design - expert 8.0 box – behnken response surface design experiment, table 2 is the test conditions and level.

Table 2. Three-factor three-level test design of response surface.

Influence factor	Code	Level		
		-1	0	1
D_{ps}	A	0.4	0.8	1.2
D_{di}	B	0.93	0.94	0.95
D_e	C	0.9	1.75	2.6

Results and Analysis

Results of the Test

The response surface analysis test of three factors and three levels of the microstructure index of solidified soil is carried out. the unconfined compressive strength q, cohesive force c and internal friction angle φ of the cured soil are used as response test results, as shown in table 3.

Table 3. Response surface test results.

Number	A	B	C	q/MPa	c/kPa	φ/°
1	1.2	0.95	1.75	1.595	568.3	40.9
2	0.8	0.94	1.75	1.598	456.7	39.8
3	0.8	0.94	1.75	1.598	456.7	39.8
4	1.2	0.94	0.9	1.583	577.2	41.6
5	0.8	0.93	0.9	1.432	489.2	37.2
6	1.2	0.94	2.6	1.596	589.3	41.1
7	0.8	0.94	1.75	1.589	456.7	39.8
8	0.4	0.94	0.9	0.895	123.9	34.9
9	1.2	0.93	1.75	1.61	568.3	40.9
10	0.8	0.94	1.75	1.598	456.7	39.8
11	0.8	0.95	0.9	1.445	488.3	40.2
12	0.4	0.93	1.75	0.982	119.2	35.0
13	0.8	0.93	2.6	1.589	323.3	39.5
14	0.4	0.94	2.6	0.992	116.8	34.7
15	0.8	0.95	2.6	1.433	320.3	39.6
16	0.8	0.94	1.75	1.522	456.7	39.8
17	0.4	0.95	1.75	0.996	118.2	35.1

Response Value and Relation Model of Each Variable

Table 4 - table 6 shows the results of variance analysis of the relationship between the unconfined compressive strength q, cohesion c, internal friction angle φ of the cured soil with design - expert 8.0.

Table 4. Variance analysis of unconfined compressive strength regression model.

Source of variation	Sum of squares	Variance	Mean square	F value	P value	Significant
Model	1.11	9	0.12	113.41	<0.0001	Significant
A	0.79	1	0.79	729.23	<0.0001	Significant
B	2.592×10^{-3}	1	2.592×10^{-3}	2.38	0.1666	
C	8.128×10^{-3}	1	2.592×10^{-3}	7.47	0.0292	
A^2	0.26	1	0.26	235.68	<0.0001	Significant
residual	4.412×10^{-3}	4	1.103×10^{-3}			
Total variation	1.12	16				

From table 4 variance analysis, it is known that $p < 0.0001$, equation regression is very significant, variable a is the key factor of unconfined compressive strength, variable b and c have less effect on the test results.

Table 5. Cohesion regression model variance analysis.

Source of variation	Sum of squares	Variance	Mean square	F value	P value	Significant
Model	5.295×10^{5}	9	58829.34	8.74	0.0046	Significant
A	1.914×10^{5}	1	1.914×10^{5}	28.44	0.0011	
B	3.00	1	3.00	4.461×10^{-4}	0.9837	
C	1.050×10^{5}	1	1.050×10^{5}	15.61	0.0055	
residual	0	4	0			
Total variation	5.766×10^{5}	16				

From the analysis of table 5 variance, it can be known that $p = 0.0046$, equation regression is significant.

Table 6. Variance analysis of internal friction angle regression model.

Source of variation	Sum of squares	Variance	Mean square	F value	P value	Significant
Model	90.42	9	10.05	36.44	<0.0001	Significant
A	76.69	1	76.69	278.17	<0.0001	Significant
B	1.20	1	1.20	4.36	0.0753	
C	0.11	1	0.11	0.39	0.5511	
residual	0.0	4	0.0			
Total variation	92.35	16				

From the analysis of table 6 variance, it is known that $p < 0.0001$, equation regression is very significant, variable a is the key factor of internal friction angle, variable b and c have less effect on the test results.

Analysis of Response Surface of Variables

According to the regression model, the surface diagram of the relationship between various variables and microstructure index of modified soil mechanics index is obtained by design - expert 8.0 software, as shown in figure 1 - 3, unconfined compressive strength q, cohesion c, internal friction angle φ and particle size distribution Dps, particle orientation Ddi, equivalent diameter De response surface are respectively.

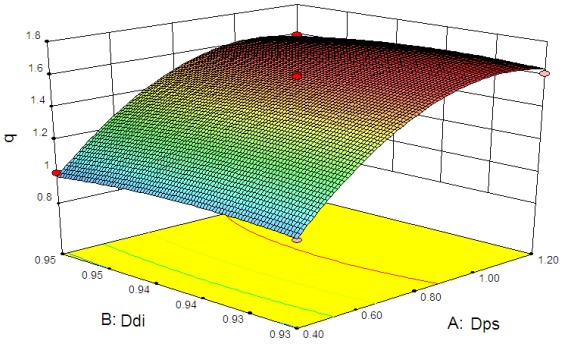

Figure 1. Unconfined compressive strength surface.

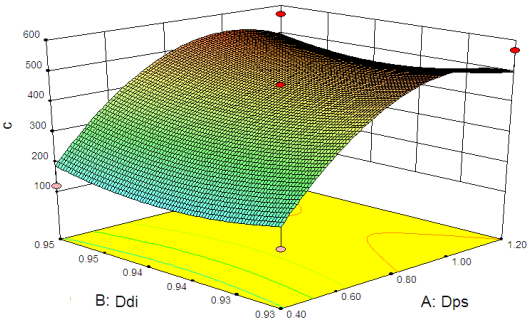

Figure 2. Cohesion curved surface diagram.

It can be seen from fig. 1 that when the particle size is fractal, unconfined compressive strength is less affected by directional fractal dimension. When the orientation fractal dimension is certain, the increase of particle size can improve the unconfined compressive strength. In other words, the worse the particles of the lime solidified coastal saline soil, the greater the unconfined compressive strength. This is mainly because: the proper amount of large particles and small particles are connected with each other, so that the structure becomes more compact and the strength increases.

Through fig. 2, it can be seen that the cohesion increases with the increase of the particle orientation fractal dimension. The more disorderly the arrangement direction of soil particles, the greater the cohesion of solidified saline soil. The main reason is that the soil particles with the particle arrangement chaos will consume some energy to conduct the particle rotation in the directional process, compared to the soil with better directional degree, the stress of the vertical displacement is decreased relative to the directional degree, and the shear strength of soil is improved obviously. When the soil orientation fractal dimension is certain, the cohesion increases with the increase of the particle size fractal dimension value. In other words, the lower the homogenization degree of the solidified saline soil particles, the greater the cohesion, which is mainly because of the cementation of some small particles into large particles, and other small particles connected with each other, make the microstructure more closely, strength increased.

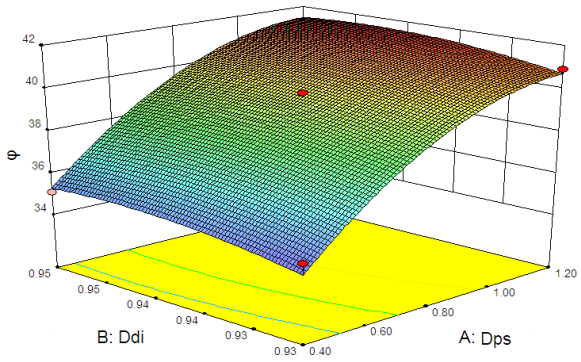

Figure 3. Internal friction angle surface drawing.

Through fig. 3, it can be seen that the internal friction angle of soil increases with the increase of particle orientation fractal dimension. When the directional fractal dimension value of the soil particle is certain, the internal friction angle increases with the increase of the particle size fractal dimension value. The main reasons are: the particles arranged in the disordered soil, the better degree of interlocking impaction between particles, and high shear resistance of the soil.

Conclusions

The experimental results show that the optimal parameters of the solidified soil microstructure are particle size fractal dimension D_{ps}, particle orientation D_{di}, and equivalent diameter of D_e, the mechanical strength index of lime solidified saline soil reaches maximum. By this model, predict the solidified soil under the condition of the unconfined compressive strength of 1.636 MPa, and the measured values are only 0.038 MPa; Cohesion of 456.7 kPa, exactly the same as that of the measured values; Internal friction Angle is 39.6 °, and the measured values are only 0.2 °.As a result, the model of the lime stabilized saline soil mechanics performance index for good forecast and analysis.

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