Experimental Study on Swelling Characteristics of Expansive Soil Stabilized by Alkali Residue

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Abstract*—In order to reduce geological disasters caused by expansive soil and recycle waste resources, industrial alkali residue were used as stabilized material in expansive soil of medium swelling potential. A series of experiments on the stabilized soil were completed and some results are as follows: (1)Atterberg limits were affected obviously with the proportion of alkali residue. The more content of alkali residue, the more plasticity limit, lower liquid limit and lower plasticity index.(2) Free swelling ratio, swelling ratios without pressure and under pressure, swelling force are reduced with increase of proportion of alkali residue. And the relation with the swelling index and the proportion of alkali residue were accord with models of negative index functions.(3) Considering the improving efficiency comprehensively, 20% was suggested as the adaptive ratio of alkali residue in expensive soil.(4) Swelling ratios without pressure was reduced quickly with setting time.The principle how alkali residue improve the expansive soil mainly lies in a portion of expansive soil replaced by alkali residue, setting and hardening of alkali residue-expansive soil, and exchangement between Ca^{2+} in alkali residue and Na^{+},K^{+} in soil.

***Keywords—** Alkali Residue; Expansive Soil; Atterberg Limits; Swelling Ratio; Swelling Pressure*

I. INTRODUCTION

The expansive soil, rich in strong hydrophilic mineral like montmorillonite and illite, is a kind of special clay formed in the natural geological process. Expansive soil is characterized by especial engineering properties, such as fissure, shrinkage and superconsolidability, which is significantly different from general cohesive soil[1]. When the water content in expansive soil changes, it will lead to the change of volume of expansive soil, resulting in expansion pressure or shrinkage cracks, therefore causing damage to industrial and building construction, railways and highways. At the same time, expansive soil hazards are often accompanied by recurrent and long-term latent features, so expansive soil is well known as “engineering cancer”[2]. How to improve the expansive soil has become one of the major global engineering problems in engineering geology and geotechnical engineering today.

There are many stabilized measures for expansive soil, commonly involving soil replacement, humidity controlling, chemical modification and pile foundation. Of course, different modified methods have different principles and characteristics. In recent years, as environmental protection issues have drawn increasing attention, scholars have started to use various types of solid wastes as improvers for expansive soils, such as fly ash, blast furnace slag, cement kiln dust, and rice husk ash [3], in order to turn waste into treasure. Mohanty M K has analyzed the effects of different ratios of fly ash (10%, 20%, 30%, 40%, 50%) on the plastic limit, swelling ratio, particle size distribution, unconfined compressive strength, CBR of expansive soil, and confirmed that fly ash is an effective modifier of expansive soil [4]. Sharma A K used blast furnace slag to improve expansive soils. It was found that the effect of curing time and blast furnace slag content on the unconfined compressive strength was not particularly pronounced, but the shear modulus increased significantly with the blast furnace slag content[5]. He also mixed fly ash and blast furnace slag particles as a cementitious material for the improvement of expansive soils. It was found that the liquid and plastic exponent of the expansive soil decreased significantly, the unconfined compressive strength increased obviously, and the best mixing ratio of modifier is 20%[6]. Salahudeen AB added 0-10% of cement kiln dust to black cotton soil in India. The experiment results showed that the maximum dry density and the optimum moisture content of modified soil reached the best when adding ratio was 6%. The ultimate compressive strength and CBR increased approximately linearly with the addition of cement kiln dust. With the increase of the coagulation period, the mechanical properties of the improved soil were improved[7]. Gupta S's study also received similar results [8]. Satyanarayana P V V(2016)analyzed the feasibility of modifying expansive soil by rice husk ash.The results showed that rice husk ash can significantly reduce the plasticity of the expansive soil and improve the soil strength. When adding 30% rice husk ash, the plastic index of expansive soil decreases to 0, the swelling rate reaches to 0 and CBR falls to 8% [9]. In addition, Liu Y Y(2017)used waste foam particles to improve the expansion and contraction of expansive soil, and achieved good performance[10].

Alkali residue is waste residue discharged by alkali production factory. Annual alkali residue generated by ammonia-soda process is up to 500 million tons in China. So it becomes a serious problem, which should been solved urgently for production factory[11]. Alkali residue is composed of calcium carbonate, calcium sulfate, calcium chloride and other calcium salts, so it can be used as soil curing materials. Sun Shulin(2012) has used alkali residue as an additive to improve the weak expansive soil, and confirmed that alkali residue had a conspicuous improvement effect[12]. Regrettably, alkali residue improvement effect influenced by curing period has not yet reported. As is well-known, which with large destructive effect in nature is generally medium or strong expansive soil.

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However, at home and abroad few researchers pay close attention to this aspect.

Therefore, aiming at expansive soil of moderate swelling capacity, through the indoor expansibility test, the effect of different mixing amount on the limit moisture content, swelling ratios without pressure and under pressure, swelling force of expansive soil are analyzed. Meanwhile, the expansion trend of deformation in different curing time are provided.

II. MATERIALS

A. *Alkali residue*

The alkali residue for test is collected from a soda plant in Huai'an, Jiangsu Province, China. In the natural state, alkali residue is gray and very pungent when approaching. After drying at 105℃, and over 10 mesh sieve, it looks like white powder, as shown in Figure 1(a), while pungent odor disappeared. The basic physical properties of alkali residue are shown in Table 1. It can be seen that the natural moisture content, liquid limit, plastic limit of alkali residue are relatively high, but plasticity index is low and expansion does not exist. The chemical composition of alkali residue is analyzed by polycrystalline X-ray fluorescence spectrometer, as illustrated in Table 2. The main cation is Ca^{2+}, Na^{+}, Mg^{2+}, and the main component is CaO. Its pH value is 8.9, which is weakly alkaline.

（a）alkali residue （b）expansive soil
Fig.1 Test material

Table 1. The physical properties of alkali residue

Chemical composition	mass fraction /%	
	alkali residue	expansive soil
CaO	52.25	5.78
SO_3	16.97	—
Cl^-	18.39	—
SiO_2	4.06	60.45
Na_2O	2.46	2.20
MgO	2.33	1.86
Al_2O_3	1.76	19.34
Fe_2O_3	1.17	3.42
K_2O	0.15	3.13
LOI	0.46	3.82

LOI : Loss on Ignition

B. *Expansive soil*

The expansive soil for test is collected from construction site in Huai'an, Jiangsu Province, China. Expansive soil is crushed into fine particles after air-dried, as shown in Figure 1 (b).

According to the standard of "Test Methods of Soil for Highway Engineering" (JTG E40-2007,China) [13], grain composition, limit moisture content, compaction characteristic and free expansion ratio were carried out. Then it can be concluded that expansive soil has moderate expansion potential.

The chemical composition of expansive soil was also tested by XRF, as list in table 2. Its main components are SiO_2 and Al_2O_3 .

Table 2. Chemical components of alkali residue and expansive soil

Dry density /g · cm^{-3}	Natural moisture content /%	Liquid limit %	Plastic limit /%	Plasticity index	Free swelling ratio /%
1.630	89.85	55.44	48.05	7.39	0

Table 3. The physical properties of expansive soil

grain composition/%				Liquid limit /%	Plastic limit /%	Plasticity index	Free swelling ratio /%	Maximum dry density /g · cm^{-3}	Optimum moisture content /%
2~0.075mm	0.075~0.005mm	0.005~0.002mm	<0.002mm						
20.35	32.49	9.44	37.72	66.3	34.7	31.6	77.2	1.47	27.0

III. TEST

A. *Mixing rate*

The mixing rate in this paper is the dry mass ratio between alkali residue and expansive soil. On account of the feasibility and convenience of sample operation, the mixing rate α is designed to be 0%, 10%, 20%, 30%, 40% and 50%.

B. *Preparation tool for sample*

Considering consistency of mixing ratio and convenience of making sample, as is shown in Figure 2, sampler was self-made[14]. The sampler adopts the half-and-half type, connected by bolts. When sampling, tester can easily obtain standard cutting ring sample if unscrewing the bolts, taking away sample-press piston conveniently and efficiently and this method can guarantee the height, flatness and uniformity of the cutting ring specimen, and make sure the consistency of same batch of samples meet the needs of the accuracy requirement of test.

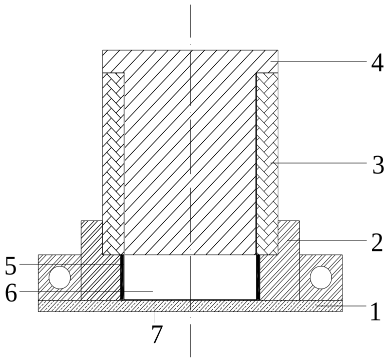

Fig.2 Sampler
(1 - base plate, 2- sample preparation drum, 3- guide, 4- pressure piston, 5 - ring knife,
6 - soil sample, 7 - circular filter paper)

C. Test Procedure

(1) After drying, the alkali residue and expansive soil are mixed according to the design ratio. And the mixture are added and stirred with water, then placed in a sealed bag, stewing for 24h.

(2) Weighing a certain amount of alkali residue - expansive soil mixture into the sampler, the soil sample will be finished by using a small press to compact and removing with a ring knife. Meanwhile, the sample surface roughness and height should be checked if reaching the requirement or not.

(3) Swelling ratio with pressure and without pressure and swelling force test are carried out. Swelling ratio without pressure test is done on WZ-2 dilatometer with YWD-50 displacement meter and DH3816 static strain measurement system to automatically and entirely collect the expansion quantity of the sample. Swelling ratio and swelling force test with pressure is done on consolidation apparatus of single lever with constant pressure of 50kPa. Load balance method was used in the swelling force test, and test procedure strictly obey "*Test Method of Soils for Highway Engineering*".

(4) Selecting a certain proportion of alkali residue - expansive soil mixture, and curing for 0,7,14,28 days respectively, expansion tests without pressure are finished to explore the influence of the setting time on the expansion and deformation.

IV. RESULTS AND DISCUSSION

A. Limit moisture content of alkali residue - expansive soil mixture

According to soil mechanics, the limit moisture content of soil is one of the sensitive indicators that reflects the interaction between soil particles and water, to a certain extent, reflecting the hydrophilic property of soil. It has a very close relationship with the composition of soil particles, mineral components, exchange performance of positive ion, soil dispersion, specific surface area. Li Shenglin has used plasticity diagram (joint use of plastic index, liquid limit) to distinguish expansive soil[15]. For this reason, the liquid limit, plastic limit and plasticity index of alkali residue-expansive soil mixture are analyzed with the change trend of the percentage of alkali residue, as shown in Fig.3. Obviously, with the increase of alkali residue content, liquid limit decreased slowly, and plastic limit increased, but when $\alpha > 20\%$, plastic limit increase limitedly. As a result, its plastic index decreases and when the mixing ratio is 20%, the plasticity index is equal to about 18, far less than the initial value of 31.6. In this case, it can be considered that the expansibility of the modified soil with a slag content of 20% is greatly reduced.

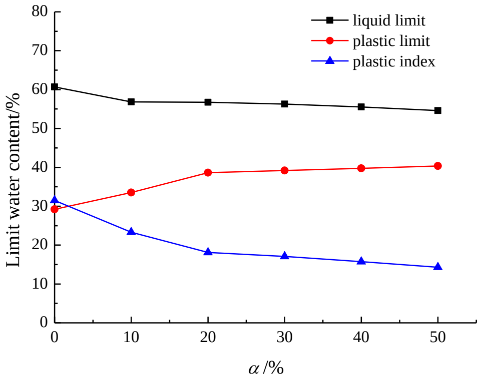

Fig.3 The relation between limit water content and mixing amount of alkali residue

B. Swelling ratio of alkali residue - expansive soil mixture

The swelling ratio of expansive soil is the key index of the expansive deformation of expansive soil. Therefore, the expansion test of expansive soil with alkali residue is carried out to investigate the variation rules of free expansion, expansion with or without pressure. The changing trend is shown in Fig.4 and some results can been got. (1) With the increase of the alkali residue ratio, the free expansion of the modified expansive soil is significantly reduced. When the mixing rate is 20%, the free expansion of the modified soil is 20.4%, which is much lower than the initial value of 77.2% and lower than 40% of the minimum limit of the weak expansive soil. (2) the also decreases with the increase of the alkali residue rate. When the mixing rate reaches 20%, swelling ratios without pressure decreases from 15.7% to 3.2%. (3) The total swelling rate of expansive soils reflects the composition and structural characteristics of clay minerals in expansive soils. Generally speaking, the total swelling rate can be approximated with the expansion at 50 kPa pressure, which is the swelling ratio under pressure in Figure 4. As can be seen from Figure 4, with the increase of the doping rate, there is a significant decrease in the dilatancy rate. When the mixing ratio is 20%, the swelling ratio under pressure is 0.45% ,less than 0.7%. According to " Specifications for Design of Highway Subgrades " (JTG D30-2015) [16], the requirements for subgrade filling are as follows: "If weak expansive soil is used as roadbed packing, it should be reformed before filling. The modified total expansion rate is not more than 0.7% ".Of course, the filler with 20% alkali residue ratio and 80% expansive soil will be able to meet the regulatory requirements.

In addition, by observing the tendency of expansion rate of alkali residue-expansive soil mixture with time, it is found that as the expansive soil is saturated with water, swelling ratio without pressure increases rapidly in about early 10 hours and then changes slowly. Generally speaking, expansion is basically completed within 50 hours.

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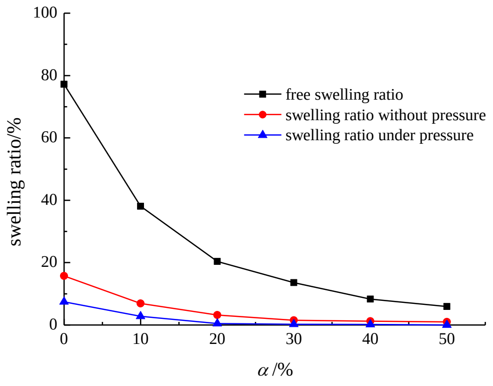

Fig.4 The relation between swelling ratio and mixing amount of alkali residue

C. Swelling force of alkali residue - expansive soil mixture

When the expansive soil absorbs water to expand, due to the limitation of the volume change, the internal stress generated in the expansive soil is the swelling force. The swelling force is the key index of structural design of retaining wall, subgrade and pavement in expansive soil area. Alkali residue doping on the impact of expansive soil law shown in Figure 5.

In order to analyze the effect of alkali residue on the swelling force, two new parameters were defined:

1) Improvement rate β : $\beta = (P_{e0} - P_{ei}) / P_{e0} \times 100\%$, where, P_{ei} expresses the swelling force after adding certain alkali residue, and P_{e0} expresses the swelling force of pure expansive soil.

2) Improved efficiency coefficient $\gamma : \gamma = \beta / \alpha$.

From Table 4 we can achieve the following conclusions:

1) With the increase of alkali residue, the swelling force of the alkali residue-expansive soil mixture sample gradually becomes smaller. In the expansive soil used in this test, the swelling force is 115.7 kPa without any alkali residue. But adding 20% alkali residue swelling force is 42.1kPa, and adding 50% alkali residue it is only 20.3 kPa.

2) With the increase of the proportion of alkali residue, the improvement rate of alkali residue improved expansive soil increases gradually. When the proportion of alkali residue is up to 20%, the improvement rate is over 50%, which shows that the improvement effect is very significant.

3) The improvement efficiency coefficient decreases with the increase of the dregs of alkali caustic, which means that the more the alkali residue, the better the economic benefit.

Combined with the limit moisture content, free swelling ratio, swelling ratio with or without pressure, swelling force and improvement efficiency coefficient of mixture with alkali residue and expansive soil, it is found that for the expansive soil with medium swelling capacity the best mixing rate is 20% .

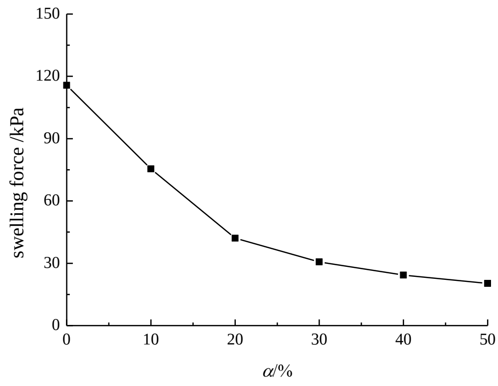

Fig.5 The relation between swelling pressure and mixing amount of alkali residue

D. Swelling ratio of alkali residue - expansive soil mixture in different setting time

Select the sample with 20% alkali residue, and carry out expansion test in the setting times of 0, 7, 14, 28 days. The conclusion can been shown in Figure 6. It can be seen that with the increase of the setting time, the swelling ratio without pressure is significantly reduced. When the setting time is 7 days, the swelling ratio without pressure has dropped to 0.9%, and the expansibility of mixture has been eliminated as the curing period is 28 days.

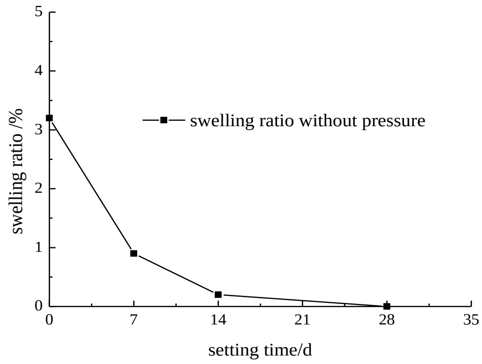

Fig.6 The relation between swelling ratio and setting time

V. CURING MECHANISM

The swelling ratio, unconfined compressive strength, shear strength and CBR of mixture with alkali residue - expansive soil show that alkali residue has significant improvement on expansive soil, and the curing mechanism mainly lies in:

A. Replacement of alkali residue

Added to expansive soil, alkali residue played a certain degree of replacement effect. Due to the low plasticity and nonexpansion of alkali residue, the replacement efficiency is more and more obvious with the increase of alkali residue content.

Table 4. The effect of treating expansive soil by soda residue

α /%	0	10	20	30	40	50
P_{ei} /kPa	115.7	75.4	42.1	30.7	24.3	20.3
β /%		34.83	63.61	73.47	79.00	82.45
γ		3.48	3.18	2.45	1.97	1.65

B. Coagulation reaction of alkali residue - expansive soil

Hydrated calcium silicate ($CaO \cdot SiO_2 \cdot nH_2O$) and hydrated calcium aluminate ($CaO \cdot Al_2O_3 \cdot mH_2O$) can be generated with CaO from alkali residue and SiO_2,Al_2O_3 from expansive soil under the water environment. The chemical product are ideal cementitious materials in the internal structure of the soil. Along with these cementitious materials gradually transforming from gel state to crystalline state, the particle size of mixture (alkali residue-expansive soil) increase, so that the strength and rigidity increase and the water stability is improved.

C. Ion exchange of alkali residue - expansive soil

Expansion and shrink of expansive soil is mainly due to water absorption of expansive mineral in soil. Once absorbing water , the thickness of water film will change. The thinner the thickness, the greater the cohesive force between the particles, the higher the shear strength of the soil, the smaller the swell-shrinking property. After added to the expansive soil and assisted by water, alkali residue is dissociated into Ca^{2+} and OH^- ions. Ca^{2+} is replaced by Na^+ and K^+ in the clay particles by ion exchange, so that the colloidal adsorption layer is thinned. As a result, the thickness of water film becomes thinner and the swelling potential of the soil reduces. In addition, alkaline environment accelerates ion exchange. As the pH of alkali residue is about 8.9, the pH value of expansive soil increases with the addition of alkali residue. Generally speaking, the more alkali residue, the more ion exchange.

VI. CONCLUSION

(1) The amount of alkali residue has some influence on the limit moisture content of expansive soil. The larger the dosage, the lower the liquid limit, the higher the plastic limit, the lower the plasticity index.

(2) The free swelling ratio, swelling ratio with or without pressure and swelling force of alkali residue-expansive soil mixture decreased significantly with the increase of the proportion of alkali residue. The expansive property index and the alkali residue ratio are approximately negative exponential relationship. The effect of coagulation on the expansibility of the mixture is also obvious. The longer the coagulation period, the smaller the expansion rate.

(3) Based on the analysis of the change law of the limit moisture content, free swelling ratio, swelling ratio with or without pressure and swelling force, it can be seen that the alkali residue has a significant improvement on expansiveness of expansive soil. Considering its improvement benefit, the amount of alkali residue is recommended as 20%.

(4) The main reasons for the expansibility of alkali residue to improve expansive soil are: the replacement efficiency of alkali residue, the coagulation reaction and ion exchange of caustic soda-expansive soil.

REFERENCES

[1] L.C.Miao, S.Y.Liu, “Engineering characteristics of expansive soil and engineering measures,” Advances in Science and Technology of Water Resource, vol.48,no.2,pp.37-40, 2001.
[2] B.T.Wang, F.H.Zhang, “The improvement technology and engineering application of expansive soil,” Beijing:Science Press, China, 2008,pp.32-35.
[3] B.Soundara, K.P.Senthil kumar, “Industrial wastes as additive for stabilization of expansive soils – a review”. Discovery, vol.41,no.186,pp.8-14,2015.
[4] M.K.Mohanty,“Stabilization of Expansive Soils Using Fly Ash”,Rourkela:National Institute of Technology ,2016.
[5] A.K.Sharma, P.V.Sivapullaiah, “Improvement of Strength of Expansive soil with waste Granulated Blast Furnace Slag,” Geocongress,2014,pp.3920-3928.
[6] A.K.Sharma, P.V.Sivapullaiah, “Ground granulated blast furnace slag amended fly ash as an expansive soil stabilizer,” Soils and Foundations, vol.56,no.2,pp.205-212, 2016.
[7] A.B.Salahudeen, A.O.Eberemu, K.J.Osinubi, “Assessment of Cement Kiln Dust-Treated Expansive Soil for the Construction of Flexible Pavements,” Geotechnical and Geological Engineering,vol.32,no.4,pp.923-931, 2014.
[8] S.Gupta, M.K.Pandey, R.K.Srivastava, “Evaluation of Cement Kiln Dust Stabilized Heavy Metals Contaminated Expansive Soil–A Laboratory Study,” European Journal of Advances in Engineering and Technology, vol.2,no.6,pp.37-42, 2015.
[9] P.V.V.Satyanarayana, C.P.Bharadwaj, P.N.Patrudu,ect, “A study on the engineering properties of expansive soil stabilized with high volume rice husk ash,” International Journal of Engineering Science and Technology,vol.8,no.4,pp.71-76,2016.
[10] Y.Y.LIU,G.Q.ZHOU,Y.H.SU,etc. “Experimental Study on Swell-shrinking Characteristics of the Mixture of Waste EPS Granules and Expansive Soil,” Industrial Construction,vol.47,no.5,pp.90-95, 2017.
[11] L.B.WANG, “Research on Engineering Properties of Soda Residue Soliified/Stabilized Heavy Mental Contaminated Soils,” Hefei :Hefei University of Technology,2016.
[12] S.L.SUN， Q.H.ZHENG， J.TANG, etc. “Experimental research on expansive soil improved by soda residue,” Rock and Soil Mechanics, vol.33,no.6,pp.1608-1612, 2012.
[13] JTG E40-2007, “Test Methods of Soil for Highway Engineering,” Beijing:China Commulications Press,2007.
[14] Y.Y.Liu,Y.Dong,P.Y,Zhu,etc.ZL 2015 2 0310914.8, 2015-08-19.
[15] S.L.Li, “Study on the engineering geology of expansive soil in China,”Nanjing:Jiangsu Press of Science and Technology,1992.
[16] JTG D30-2015, “Specifications for Design of Highway Subgrades, ”Beijing:China Commulications Press,2015.