Research on Swelling Characteristics of a Mixture of Waste EPS Particles and Expansive Soil Impacted by Initial Water Content

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KEYWORD: expansive soil; waste EPS particles; initial water content; swelling ratio without pressure; swelling ratio under pressure; swelling force

ABSTRACT: The swelling characteristics of a mixture of waste EPS particles and expansive soil are influenced significantly by initial water content. In order to search out the influential regularities under different initial water content, the tests of swelling ratio without pressure, swelling ratio under pressure and swelling force are conducted. The experiments result in valuable conclusions as follows. First of all, the swelling ratio without pressure and swelling ratio under pressure of the mixture increase gradually in the process of absorbing water and saturating, and swelling curves have experienced the following three stages: rapid expansion, slow expansion and stable period. Furthermore, the smaller initial water content is, the shorter rapid expansion period continues and the faster the swelling rate becomes. What's more, the experimental data demonstrate a linear negative correlation between swelling ratio (without pressure or under pressure) and the initial water content. The expansive force changing with the initial water content is nonlinear, reached the maximum when the initial water content is close to the optimum moisture content.

INTRODUCTION

Expansive soil is a sort of special clay formed in the natural geological process, whose composition includes strong hydrophilic mineral montmorillonite and illite with engineering characteristics of overconsolidation and developing fissures as well as the features of swelling and softening by absorbing water shrinking and cracking by losing water and repeated changing. Due to its poor engineering characteristics, it often seriously damages industry and the superficial layer engineering facilities such as buildings, highways, railways, airports and water conservancy, and it refers to "cancer" in engineering since the damages are repetitive and latent in the long-term. Expansive soil is widely distributed in China, especially in the Midwest part, such as Guangxi, Yunnan and Henan province(ZHENG,J.L& YANG,H.P. 2009). With the implementation of the strategy of west development of China, highways and railways are quickly extended to the central and western regions, whose construction and operation face terrible geological disasters caused by expansive soil. Relevant experts have attached great importance to this phenomenon.

The common methods to improve expansive soil are replacing method, chemical modification, humidity control and pile foundation(WANG,B.T & ZHANG,F.H. 2008; Radhey,S.S. & Bhyravajjula,R.P. 2005). Since the 1990s, scholars around the world began to try some new modified technology, and some found it effective to inhibit swelling and reduce the expansive force if adding construction fiber in expansive soil, and the effect has a lot to do with the amount and draw ratio of construction fiber(Puppala, A. & Musenda, C. 2000; Miller, C. J. et al. 2009). In recent years, the scholars aim at the research of recyclable solid waste, so fly ash and blast furnace slag are applied(Nalbantoğlu, Z. 2004; Manjunath,K.V. et al.2012). In addition, some scholars have studied properties that the waste tire rubber powder modified expansive soil, and analyzed the relationship between shear strength of expansive soil and amount and water content and of tire rubber powder(Seda,J. H. et al. 2007; SUN,S.L. et al.2009). Compared with fly ash, blast furnace slag and waste tire rubber powder, waste polystyrene foam plastic particles (EPS particles) is a kind of ideal improving material because of its lightweight, high compressibility, good stability, long durability, low moisture absorption and heat preservation(Illuri,H.K. & Nataatmadja,A. 2007). However, few research in this field is reported currently.

The author has written articles about properties that waste EPS particles improve expansive soil, so will not elaborate here. Since the swell-shrink characteristic and the original state of expansive soil is closely bound up to its moisture content(DAI,Q.L.et al.2008), based on medium swelling potential expansive soil, this paper deeply analyses expansion rate and the changing rule of the ESP particles-expansive soil mixture under the condition of different water content through the indoor swelling tests, hoping to provide reference to the design and construction of subgrade of expansive soil and retaining structure.

EXPERIMENTAL MATERIALS

Basic properties of expansive soil

The expansive soil used in the test is taken from Xuyi, Huai'an with gray color and strong plasticity that is made into fine granular by mill grinding after dried. Its content of particle groups and liquid-plastic limit are tested with reference to *Test Method of Soils for Highway Engineering*(JTG E40-2007), and its basic physical properties are shown in Table 1. The liquid limit of expansive soil here is greater than 50%, and it belongs to the high liquid limit clay.

Adopting free swell ratio tester, two sets of parallel tests were carried out, and respectively get 86.6% and 87.4%, as the results, the average is 87.0%. According to *Technical Code for Building in Expansive Soil Regions*(GB 50112-2013) , expansive soil used in the test can be judged as medium swelling potential.

Table 1. Basic properties of expansive soil

Grain group content /%			Liquid limit w_L /%	Plastic limit w_P /%	Plastic index I_P
2~0.075mm	0.075~0.005 mm	<0.005 mm			
23.84	64.32	11.84	77.7	27.9	49.9

According to *Test Method of Soils for Highway Engineering*, a standard compaction test was taken in expansive soil, and tested the best moisture content is 21.2%, and the maximum dry density is 1.53 g/cm$^{3.}$

ESP particles density

Wasted polystyrene plastic is taken from foam canister for package in local salvage stations of Huai'an. As shown in Figure 1, the necessary foam particles in the test were rubbed from foam canister by hand. According to the method given in the literature(LIU,Y.Y. et al.2015a), the device was designed to test the EPS particle packing density of 0.020 g/cm^3 based on the linear relation between bulk density (0.013 g/cm^3) and particle density.

Figure 1. Wasted ESP particles

TESTING PROGRAM

The initial dry density control

When construction quality of subgrade and pavement is tested, degree of compaction is one of the key indicators which reflects compaction condition after subgrade was filled with soil and compacted concretely. The higher the degree of compaction and the density is, the better whole performance of subgrade will be. According to compaction control standard for highway（≥96%）, the degree of compaction of expansive soil used in the test is strictly controlled at 98%, that is to say, initial dry density of the sample is designed at 1.50 g/cm^3.

Initial water content design

According to feasibility and operability of the sample, as is shown inTable 2, the initial water content w_0 of the expansive soil in the test is designed into 4 kinds: respectively 15%、20%、25%、30%.

Table 2. The initial water content of four samples

Group number	Initial water content w_0（%）
A	15
B	20
C	25
D	30

Preparation tool for sample

Considering consistency of the EPS particles and convenience of making sample(LIU,Y.Y. et al.2015b), as is shown in Figure 2, sampler was self-made. 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.

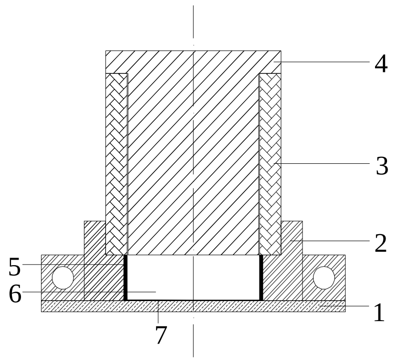

Figure 2. Sampler
(1 - base plate, 2- sample preparation drum, 3- guide, 4- pressure piston, 5 - ring knife, 6 - soil sample, 7 - circular filter paper)

Test procedures

(1) The soil samples are prepared according to initial water content, and placed in the bag for 24h.

(2) According to the previous test conclusion, 10% soil samples are chosed as waste EPS particle to compared with the volume of expansive soil. For swelling test, the volume of each ring knife sample is fixed of of average 60 cubic centimeter, so the quality of the EPS particles in each sample is m_{EPS}=60×10%×0.013=0.078g, and the quality of the expansive soil m_{es} =60×90%×1.5×w_0, and then corresponding EPS particles and expansive soil are weighed and mixed.

(3) As shown in Figure 3, pour the EPS particles-expansive soil mixture into sampler, press soil samples with stripper and take out the ring knife sample to check if roughness and height of the sample surface meet requirements.

Figure 3. Sample finished

(4)Carry out swelling ratio with pressure and without pressure and expansive force test. 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 expansive force test with pressure is done on consolidation apparatus of single lever with constant pressure of 25kPa. Load balance method was used in the expansive force test, and test procedure strictly obey *Test Method of Soils for Highway Engineering*.

RELATIONSHIP BETWEEN CHARACTER OF WASTE EPS PARTICLES - EXPANSION SOIL MIXTURE AND INITIAL WATER CONTENT

Swelling ratio without pressure

Process curve of swelling ratio without pressure can be shown in Figure 4. It is thus clear that with the expansive soil absorbing water and saturated, changes of swelling ratio without pressure can be roughly divided into three stages: (1) rapid expansion period. In general, this stage will be finished in 5 hours after the expansive soil absorbing water. And the swelling amount is large, accounting for about 60%—80% of the total. By comparison, it shows that the smaller the initial water content and the shorter rapid expansion period is, the faster the expansion rate will be. (2) Slow expansion period. In this stage, expansion rate is becoming slow and will be finished in about 5-20 hours, and the smaller the initial water content is, the period will last longer. (3) Stable expansion period. After expansive soil absorbing water and saturated, its density is less, and the space between the soil is lager and lager. The time of the water completely filling the space is more, so the expansion period last longer. But not change is slight, the curve is relatively stable.

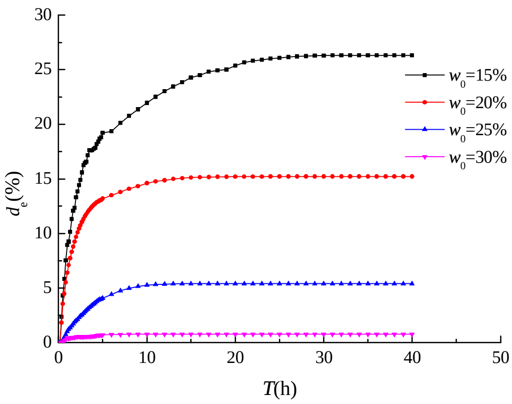

Figure 4. Process curve of expansion ratio without pressure

As is shown in Figure 5, in the end, swelling ratio without pressure decreases with the increase of initial water content, and in the four samples, maximum rate is 26.31%, and the minimum is only 0.79%. It is clear that initial water content obviously influence swelling ratio without pressure of waste EPS particles - expansion soil mixture.

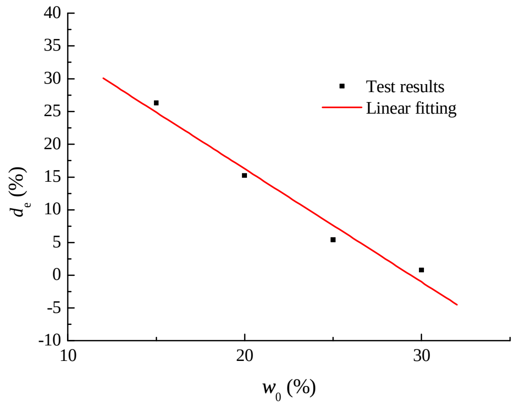

Figure 5. Relationship between swelling ratio without pressure and initial water content

According to regression analysis, matching relationship between initial water content and swelling ratio without pressure is as follow:

$$d_e = -1.73w_0 + 50.80 \quad (1)$$

where d_e——swelling ratio without pressure(%); w_0——initial water content(%).

Correlation coefficient R^2= 0.956 shows swelling ratio without pressure of waste EPS particles - expansion soil mixture and initial water content present a good linear relationship.

Swelling ratio under pressure

Constant pressure of each sample in swelling ratio under pressure test is 25kPa, and variation trend of EPS particles visible-expansive soil with different initial water content is shown in the Figure 6. Figure 6 shows that swelling ratio under pressure non-linearly increases with time goes, which is similar with the law of swelling ratio without pressure. It also experienced three stages: rapid expansion period, slow expansion period and stable period. At the same time, the smaller the initial water content is, the lager the swelling ratio under pressure is. While w_0 was 15%, the swelling ratio under pressure reached 9.60% in the end and while w_0 was 25%, the swelling ratio under pressure decreased to 1.18%.

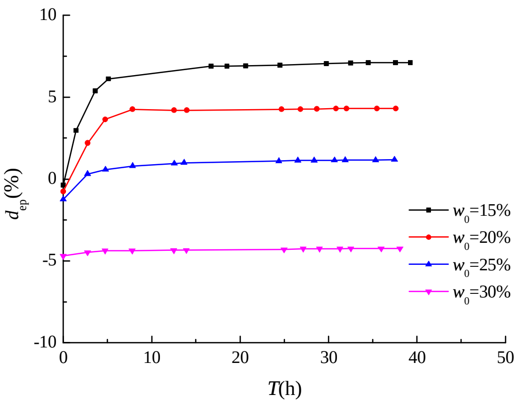

Figure 6. Process curve of swelling ratio under pressure

There is a noteworthy phenomenon: at the very beginning of the swelling ratio under pressure test, that is to say, when pressure is 25kPa, four samples all appear compression (swelling ratio is a negative inflation rate). And the larger initial water content is, the amount of compression is greater and compression ratio of the sample with w_0 of 30% reached 4.7%. With expansive soil swelling, compression ratios of the other three samples with w_0 of 15%, 20%, 25% are increasing and lager than pressure so that compression ratio changes gradually to be positive until stable. But due to limited water quantity, compression ratio of the sample with w_0 of 30% is relatively small, just at about 25kPa, which leads to its compression ratio inflation remains between 4.2%~ 4.5%.

In addition, under the condition of constant pressure of 5kPa, compared the swelling ratio under pressure with the swelling ratio without pressure, the two of the three samples with w_0 of 15%、20%、25% are respectively 27.0%、28.3%、21.8%, which shows inhibiting effect of upper pressure is very obvious.

Eventual relationship between swelling ratio under pressure and initial water content is shown in Figure 7. And by regression analysis, there fitting relationship is:

$$d_{ep} = -0.74w_0 + 18.80 \qquad (2)$$

where d_{ep} ——swelling ratio under pressure（%）.

Correlation coefficient R^2=0.9597 shows under the condition of constant pressure of 25kPa, swelling ratio under pressure of waste EPS particles visible - expansive soil mixture and initial water content present a good linear relationship.

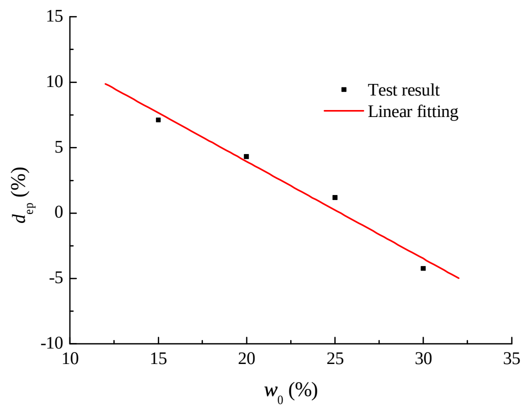

Figure7. Relationship between swelling ratio under pressure and initial water content

Expansion force

When expansive soil is absorbing water and expands, due to the limited volume change in expansive soil, its internal stress is expansion force. In this test, load balance method is adopted, its equipment is the same as the uniaxial oedometer, and standard sand and sand bucket are replaced with weights and hanging scaffold so that it will be accurate and controllable when adding pressure. The test results are shown in table 3 and figure 8.

It is visible that expansion force of sample B（w_0=20%）of the four samples of waste EPS particles visible - expansive soil mixture is the largest of about 112.46kPa, because initial water content and initial dry density of sample B are close to the best with relatively bigger degree of compaction and less space, and the effect to limit the volume change is most obvious. While expansion force of sample D is the smallest of 26.22kPa, which is fair with the pressure given in the test of swelling ratio under pressure. And it explains why swelling ratio under pressure remains stable within certain limits when w_0=30%.

Table 3. Test results of expansion force

Group number	Initial water content w_0（%）	Expansion force P（kPa）
A	15	82.56
B	20	112.46
C	25	57.60
D	30	26.22

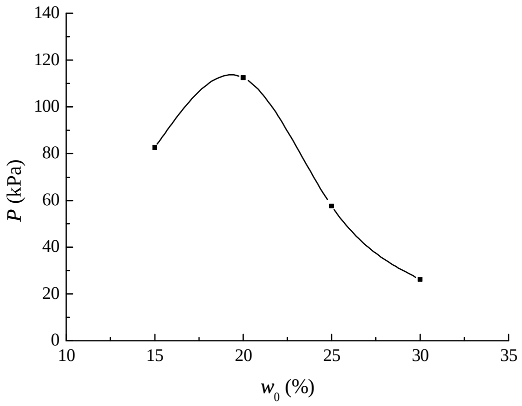

Figure 8. Relationship between expansion force and initial water content

CONCLUSIONS

A series of indoor swelling test were carried out with waste EPS particles - expansion soil mixture. The changing rules of swelling ratio and expansion force under the conditions of different initial water content were deeply analyzed and the conclusions are as follows:

(1) With the expansive soil absorbing water and saturated, swelling ratio with or without pressure is increasing and experienced three periods: rapid expansion, slow expansion period and stable period.

(2) The smaller the initial water content is, at the same time swelling ratio with or without pressure of waste EPS particles-expansion soil mixture is larger, and the shorter rapid expansion period and the faster the expansion rate will be.

(3) Inhibiting effect of upper pressure toward waste EPS particles - expansion soil mixture is very obvious. The initial water content is larger, the inhibition effect of upper pressure is more prominent.

(4) Swelling ratio with or without pressure linearly decreases with the increase of initial water content, while expansion force changes nonlinearly and approaches the maximum when the initial water content reaches the optimum moisture content.

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