EXPERIMENTAL STUDY ON ONE-DIMENSION COMPRESSION AND CREEP CHARACTERISTICS OF EXPANDED POLYSTYRENE (EPS) IN THE APPLICATION FOR STABILIZING SLOPE OF EXPANSIVE SOIL CANAL

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ABSTRACT

Expanded polystyrene (EPS) geofoam is a novel kind of geosynthetic material, which has some prominent features, e.g. light weight, compressibility well, water resistant and heat preservation. Therefore, EPS can be used as a lining structural layer of underwater slope of expansive soil canal to reduce expansive pressure acting on concrete lining face slab and maintain matric suction of expansive soil, thus make the slope of expansive soil canal more stable. In order to further explore the mechanical characteristics of EPS under compression in this application, a set of one-dimensional compression tests and compressive creep tests on EPS with three different densities (14.7kg/m^3, 17.05kg/m^3, 23.4kg/m^3) were conducted, the experimental results show that the stress-strain relationship of EPS is significantly nonlinear and the creep strain is significant under long-term loading. Based on the experimental results, a mathematical model for describing the whole compression process of EPS is proposed.

Keywords: Expanded polystyrene (EPS), compression, creep, constitutive model, expansive soil canal slope

INTRODUCTION

Expansive soil will expand when absorbing water, the amount of expansion is relevant to the stress state. If the loading pressure is equivalent to the expansive stress, the expansive ratio is zero (namely no expansion), the expansive ratio increases as the loading pressure decreases. The method of concrete lining face slab combining with glass fiber reinforcement plastic (GFRP) screw anchor was successfully adopted to stabilize a underwater slope of expansive soil canal (Wang et al, 2007, Zou et al, 2009). Expansive polystyrene (EPS) is highly compressible, if EPS is placed under concrete lining face slab, expansive soil is allowed to expand to some extent, thus the expansive force acting on underwater concrete lining face slab can be reduced, which may prevent the concrete slab from being damaged.

Besides, EPS has low thermal conductivity, thus it is usually applied as heat retaining panel in canal anti-freezing engineering. EPS is also water resistant. Because there are gas phase and shrink film in unsaturated soil, the variation of temperature has much greater impact on the mechanical characteristics of unsaturated soil than that of saturated soil. From the thermodynamics theory of inflation, we know that properties of gas phase and shrink film are much more relevant with the variation of temperature than solid phase and liquid phase. In thermodynamics, matric suction is a function of temperature. As temperature rises, the soil-water characteristic curve (SWCC) moves leftward, which means that the retention capacity of soil decreases (Wang et al, 2011, Wu et al, 2004), Tang et al, 2005). When the water content is constant, the matric suction decreases as the temperature rises. For unsaturated soil, as the temperature rises, the range of elasticity decreases, the compressibility increases and the shear strength decreases. But some other literature shows that the rise of temperature causes the increase of matric suction and shear strength (Krishnaiah et al, 2003, Xie et al, 2005). Therefore, the heat resistant, water resistant and highly compressible properties of EPS are very useful for reducing expansive force, preserving matric suction and then stabilizing expansive soil canal.

The compressive characteristic is very important when EPS is applied to reduce expansive force acting on concrete lining face slab of underwater slope of expansive soil canal. Several researchers have already studied this topic. Chung et al (2004) proposed a hyperbolic constitutive law based on the triaxial tests.

Hazarika (2006) came up with a constitutive model based on the plasticity theory. Mao et al (2007) conducted a compressive creep test of EPS. According to Mao's experiment, creep of EPS has three stages: initial instantaneous elastic stage, transitional creep stage and steady creep stage. Based on triaxial tests and fatigue tests, Ling et al (2003) proposed a piecewise constitutive model. However, there are still some shortages of current research. Firstly, there is no constitutive model that can describe the full process of compression of EPS. Secondly, in the application of expansive soil canal stabilization, the loading on EPS is small and the time is long, there are few results of long time creeping tests of EPS under low loading level in the existing literatures.

To improve the deficiencies of current studies, results of a set of unconfined one-dimensional tests of EPS with three different densities were presented and a mathematical model, which describes the full process of compression of EPS and includes the effect of density variation of EPS, was proposed. In the meantime, long time creeping testing results of EPS with three different densities under low load level are also introduced.

UNCONFINED ONE-DIMENSIONAL COMPRESSIVE PROPERTY AND MATHEMATICAL MODEL OF EPS

Unconfined One-Dimensional Compression Tests.

The shape of each specimen was cube of L50mm*W50mm *H50mm. The specimens were of three different densities(14.7、17.05、23.4kg/m^3). The tests were conducted on REGER material testing apparatus. The loading speed was 5mm/min. The stress-strain curve is shown in Fig. 1.

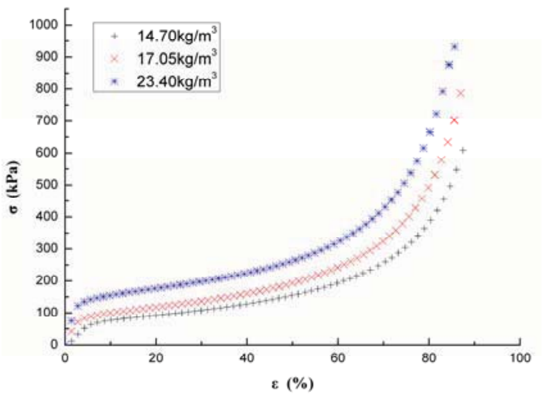


Fig. 1 The stress-strain curve of unconfined one-dimensional compression of EPS.

From Fig. 1, the following statements can be obtained:

(1) The stress-strain curve of EPS is significantly nonlinear. Initially, the curve is straight. With the increment of stress, the slope of the curve decreases. Afterwards, when stress keeps increasing, the slope of the curve increases again, especially when the strain is over 60%, the slope of the curve increases dramatically.

The above compressive characteristic is determined by the material property of EPS. There are numerous voids in EPS. In the process of compression; the voids are under compression until ruptured. When the loading level is below a certain critical value, the voids have not been ruptured yet and he EPS is still elastic. Once the load level exceeds a certain value, the voids begin to rupture and EPS begins to yield. When the voids are totally ruptured, the EPS is plastic. If the load continues to increase, the ruptured voids are further compressed. At this time, the EPS can be seen as a block of polystyrenes without voids, it is approximately elastic.

For the sake of simplicity, the full process of compression can be generalized into two stages: (1) The voids are being compressed until ruptured, while the slope of stress-strain curve is decreasing. (2) The voids are further compressed, while the slope of stress-strain curve is increasing.

(2) As the density of EPS increases, the stress of a certain strain also increases. This is because EPS with larger density has less voids and pure polystyrene without voids has greater strength. On the other hand, as the density decreases, the strain of a certain stress increases. In other words, low density EPS is more compressible. Therefore, in order to reduce expansive pressure acting on the concrete lining face slab of expansive soil canal, it is better to choose low density EPS. According to existing literatures and application experiences, density of EPS has also impact on its heat resistant ability and water proof ability, thus it is appropriate taking these two factors into account when choosing the density of EPS.

Mathematical Model to Describe the Compression Process of EPS

Considering the characteristics of the stress-strain curve of EPS, a piecewise function can be used to describe the compression process of EPS. At the first stage, when the slope of curve decreases, the compression process of EPS can be described by hyperbolic function; at the second stage, when the slope of curve increases, the compression process of EPS can be described by exponential function (shown in Eq. 1).

$$\sigma=\begin{cases}\dfrac{\varepsilon}{1/E+(1/E_1)\varepsilon} & ,\varepsilon<\varepsilon_0 \\ \sigma_0+A(e^{R(\varepsilon-\varepsilon_0)}-1) & ,\varepsilon\geq\varepsilon_0\end{cases} \quad (1)$$

where σ_0 and ε_0 are the stress and strain at the inflection point. For the EPS used in the testing, the strains at the inflection point are all 20%. E, E_1, A, R are coefficients that are relevant to density of EPS, which are show in Table 1 by using Eq. 1 to fit the experimental data.

Table 1 Coefficient values for Eq. (1)

Density of EPS/kg·m^{-3}	14.7	17.05	23.4
E/MPa	2.009	5.767	10.467
E_1/MPa	0.122	0.130	0.187
A/MPa	0.0118	0.0123	0.0126
R	5.61	5.98	6.3

A linear function (Eq. 2) can be used to express the relationship between these coefficients and density of EPS.

$$\begin{cases}E=0.826\rho-9.3515 \\ E_1=0.0071\rho+0.0136 \\ A=0.00007\rho+0.011 \\ R=0.0653\rho+4.743\end{cases} \quad (2)$$

Equations 1 and 2 are mathematical model that describes the full compression process of EPS, this model takes the influence of density of EPS into account. The fitted data and experimental data are compared in Fig. 2. The comparison shows that this model can describe the full process of compression characteristics of EPS well.

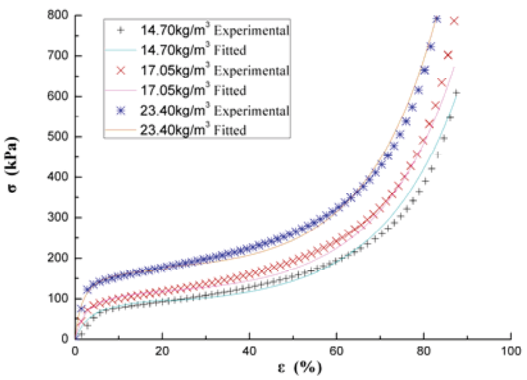
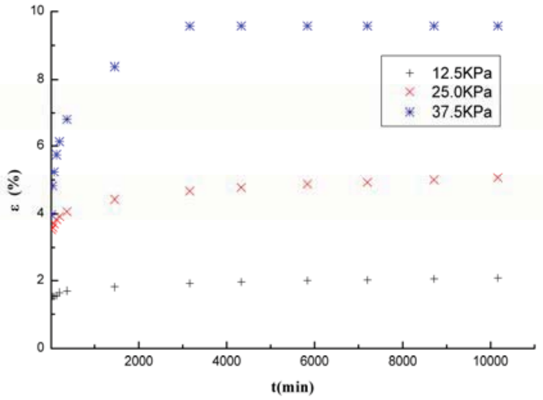


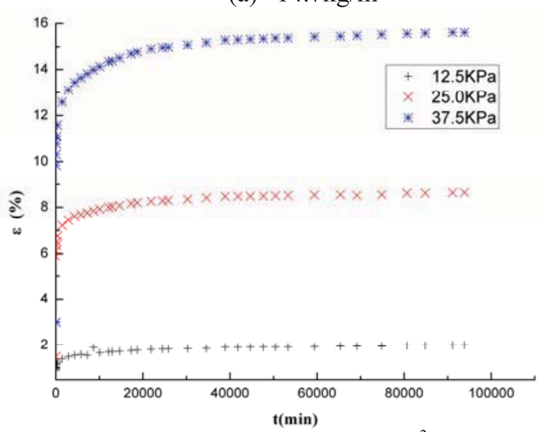
Fig. 2 Comparison between fitted data and experimental data

COMPRESSIVE CREEP CHARACTERISTIC OF EPS

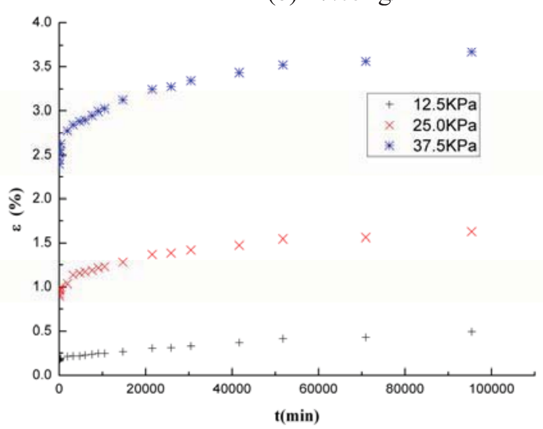
Unconfined compressive creep tests were conducted on high pressure consolidation apparatus. The specimens were cylinders with diameter of 80mm and height of 10mm. The specimens were unconfined. The specimens were of three kinds of densities(14.7、17.05、23.4kg/m^3). There were three kinds of vertical load: 12.5kPa, 25kPa, 37.5kPa, which were similar to the weight of concrete lining face slab of expansive soil canal. The results of compressive creep tests are shown in Fig. 3.



(a) 14.7kg/m^3



(b) 17.05kg/m^3



(c) 23.4kg/m^3

Fig. 3 Creep curves of EPS with different Densities

From the creep curves of EPS with different densities, the following statements can be obtained:

(1) There is an instantaneous strain at the beginning, and then the creep occurs gradually. The total creep strain is very large compared with the instantaneous strain. The total creep strain can be 2 or 4 times of the instantaneous strain and the maximum value among EPS of three densities is 15%. Therefore, in practical engineering application, the creep strain of EPS cannot be neglected. In the tests of this paper, although the load is small, the creep strain is still significant after long time. If EPS is placed under concrete lining face slab of expansive soil canal, the weight of concrete slab and internal hydraulic pressure from canal will cause significant creep strain; this strain will cause the deformation of lining structure, which will affect the normal use of the canal. In practical engineering, the creep strain has to be taken into account.

(2) The velocity of creeping is large at the beginning, then decreases, and is stable in the end.

(3) For EPS of a same density, larger load causes larger creep strain.

(4) Under a same load, for EPS with larger density, it takes longer time for the creep strain to become steady.

CONCLUSIONS

(1) The stress-strain behaviour of EPS under one-dimensional compression is significantly nonlinear. The process of compression can be separated into two stages: (a) The voids are being compressed until ruptured, while the slope of stress-strain curve is decreasing. (b) The voids are being further compressed, while the slope of stress-strain curve is increasing. Eq. (1) and Eq. (2) are mathematical model that describes the full process of compression of EPS.

(2) Low density EPS is more compressible. Therefore, in order to reduce expansive stress, it is better to choose low density EPS. But the density of EPS has also impact on its heat resistant ability and water proof ability, thus it is appropriate take these two factors into account when choosing the density of EPS for the application of ling structural layer of expansive soil canal.

(3) Larger load causes larger velocity of creeping. For EPS with larger density, it takes longer time for the creep strain to become steady.

(4) Under long-time load, there will be significantly creep strain even the load is small. If EPS is placed under concrete ling face slab in expansive soil canal, the weight of concrete slab and internal hydraulic pressure from canal will cause significant creep strain of EPS, which will cause the deformation of lining structure, and affect the normal use of the canal. So the creep strain of EPS has to be taken into account.

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REFERENCES

Chung B.S., Limb H.S., and Sagongc, M. (2004). Development of a hyperbolic constitutive model for expandedpolystyrene (EPS) geofoam under triaxial compression tests. Geotextiles and Geomembranes, 22 : 223-237.

Hazarika H. (2006) Stress-strain modeling of EPS geofoam for large-strain applications. Geotextiles and Geomembranes, 24 : 79-90.

Tang A. M., and Cui Y. J. (2005). Controlling suction by the vapour equilibrium technique at different temperatures and its application in determining the water retention properties of MX80 clay. Canadian Geotechnical Journal, 42(1): 287-196.

Krishnaiah S., and Singh D. N. (2003). A methodology to determine soil moisture movement due to thermal gradients. Experimental Thermal and Fluid Science, 27: 715–721.

Ling J.M., Wu Z., Ye D.W., and Qian Z.B. (2003). Constitutive law and fatigue characteristics of expanded polystyrene under uniaxial compression. Journal of Tongji University, 31(1): 21-25 (in Chinese)

Mao K., and Zhang J.Y. (2007). Experimental research on compression creep of expanded polystyrene. Materials Review. 21: 468-470

Wang Z., Qiu, Z. Q., Cai S. T., Hu H. L., Cui B. J., and LU Y. (2007). A case history of application of FRP screw anchor and geosynthetics in repairing of canal slope of expansive soils. Sout-h to Nort-h Water Transfers and Water Science & Technology, 5(5): 127-131. (in Chinese)

Wang X.Q. Zou W.L., Luo Y.D., Wang J.F., and Deng W. D. (2011) SWCCs and influence of temperature on matrix suction under different compaction degrees. Chinese Journal of Geotechnical Engineering. 33(3): 368-372. (in Chinese)

Wu H W, Li X K, and R. Collin C, F. (2004) A thermo-hydro-mechanical constitutive model and its numerical modeling for unsaturated soils. Computers and Geotechnics, 31: 155–167.

Xie Y, Chen Z.H, and Li G.(2005). Research of thermal effects on shear strength and deformation characteristics of unsaturated bentonite soils. Chinese Jounal of Geotechnical Engineering, 27(9): 1082-1085. (in Chinese)

Zou W. L. Wang Z., and Chen C. H. (2009). Field pull-out tests and failure model of GFRP screw anchors used to stabilize canal slopes of expansive soils. Chinese Journal of Geotechnical Engineering, 31(6): 970-974 (in Chinese)