Geotech Geol Eng (2021) 39:4341–4353
https://doi.org/10.1007/s10706-021-01765-4

ORIGINAL PAPER

One-Dimensional Compression Creep Characteristics of Light Weight Soil Mixed with Weihe River Mud and EPS Particles

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Received: 3 August 2019 / Accepted: 19 February 2021 / Published online: 2 March 2021

Abstract In order to reveal the creep laws of light weight soil, the compression creep characteristics of light weight soil mixed with Weihe River mud and EPS (expanded polystyrene) particles are researched by one-dimensional compression creep tests. The results show that the cementation structure strength of light weight soil becomes larger, and the creep deformation under the same load becomes smaller with the increasing of cement content and the decreasing of EPS particles content. For the same mixed ratio of light weight soil, when the load is larger, the deformation is greater, but the time of the deformation reaches the steady stage is shorter. With the increasing of the time, the deformation is increasing, finally it tends to be a stable value. There is no sharp creep stage, the deformation is attenuated creep. Light weight soil is a kind of structural soil, and it has a certain compression yield stress. When the load acting on the specimen is less than the compression yield stress of light weight soil, its cementation structure may still be intact, but the deformation is mainly due to the discharge of pore water and the movement of solid particles, and therefore deformation is small. When the load is greater than the compression yield stress of light weight soil, the cementation structure might have been collapsed, there is larger deformation for the EPS particles under pressure, the deformation of the samples is mainly the plastic deformation of the EPS particles, and therefore deformation is large. In the practice, the load should be controlled within the compression yield stress of light weight soil. According to the results, a power function empirical creep model is set up. Compared the test data with the model calculation data, it is found that when the axial load is less than the compression yield stress, the model can exactly reflect the creep laws of light weight soil in a certain time scale (e.g. 50 years), and it can provide a theoretical basis for the practical engineering.

Keywords Light weight soil · Creep properties · One-dimensional compression creep tests · Creep model

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1 Introduction

With the development of society, plastic products are used widely for their convenience by people in daily life. However, because of the low secondary utilization rate of plastics, white pollution has become a major problem in the twenty-first century. In addition, due to the serious soils erosion on the Loess Plateau, the river mud deposits, floods and other disasters occur frequently. A new type of light weight filling which is called EPS particles light weight soil can be made from waste expanded polystyrene (EPS) particles, Weihe River mud, a certain amount of curing agent (such as cement, fly ash, etc.) and water. Compared with ordinary soil, EPS particles light weight soil has the characteristics of small density, high strength, and the density and strength can be adjusted according to engineering needs (Akbulut and Pamukcu 2010; Pamukcu and Akbulut 2006). EPS particles light weight soil can be applied to foundation filling, such as highway subgrade and railway subgrade, and it can alleviate white pollution effectively, realize waste utilization, save cost, and have a good development and application prospect.

As a new type of material, EPS particles light weight soil has been concerned and studied by many scholars (Hou 2012b, 2014). Japanese have many research achievements in this area, and use light weight soil generally in engineering. Chinese have also made some breakthroughs in the study of light weight soil. In terms of sand and clay creep, the creep properties of saturated sand are discussed through indoor consolidation tests (Zhang et al. 2005). The test results show that the sand has significant creep properties. The creep deformation stability time of the sand increases with the increasing of stress, and the creep deformation is nonlinear. In 2013, the creep properties of the sandy slate coarse-grained soil roadbed filling are studied through large scale one-dimensional compression creep tests under low stress conditions (σ = 50, 100, 200, 400, and 800 kPa) (Nie et al. 2013), and the creep model parameters of sandy slate coarse-grained soil with 95% compaction degree are obtained. The results show that the elastic deformation, stable creep and non-viscous flow of coarse-grained soil gradually decrease under low stress. In 2014, the influence factors of creep properties of coarse-grained soil are studied through one-dimensional compression creep tests (Han et al. 2014), the results indicate that the water content and fine particles soil content are important influence factors of the creep properties for coarse-grained soil. In addition, it is proposed that dry or saturated coarse-grained soil with 30% content fine-grained soil can be used to control the long-term settlement of the embankment. In order to study the change laws of shear strength, miniature vane shear tests of ten samples are carried out (Yang et al. 2014). The creep properties of soils are influcenced by many factors under different stress conditions, so the soil displays different mechanical behavior. The results show that the one-dimensional compression creep duration curve has a nonlinear characteristics, and the stress–strain isochronous curve is closed to the stress axis with the increasing of stress. In the one-dimensional compression condition, the compression modulus is positively correlated with time, and the long-term strength firstly increases and then tends to be stable.

In terms of creep characteristics of slip zone soil, the creep tests of the slip zone soil of the Dayantang landslide are carried out under 300, 500, 625, 800, 1000 kPa consolidation pressure (Yan et al. 2008), the creep curves under different pressure and shear stress are confirmed, and the long-term strength of slip zone soil is about 0.76 $\sim$ 0.77 times that of the slow shear strength. In 2012, the creep curves under different deviatoric stress and matrix suction are obtained through unsaturated triaxial creep tests (Lai et al. 2008). The results show that the creep deformation and the creep rate increase with the decreasing of matric suction when deviatoric stress is the same, and the increase range is positively correlated with the deviatoric stresses. In 2013, the slip zone soil creep properties of the Qianjiangping landslide are studied through unsaturated triaxial creep tests (Zou et al. 2013). The Burgers creep model for unsaturated soil under triaxial stress condition is considered and revised. The residual creep properties of typical clay soil are studied through using an improved torsional ring shear apparatus (Bhat et al. 2013). The results show that the improved instrument can be used to measure the variation laws of displacement with time increase under constant stress. The creep failure predicted curve is proposed in residual creep state, it can be used to predict failure time and failure displacement of landslides creep. In 2014, the creep properties of landslide body soil are studied through triaxial creep tests under different confining pressure and different stress level (Hu et al. 2014). The results show that there are two stages for the coarse-grained soil in creep process: deceleration creep and uniform creep, which exhibits nonlinear creep characteristics.

In terms of creep characteristics of soft soil, the influence of organic matter contents and the curing condition on the one-dimensional compression characteristics of Portuguese solidified soft soil are studied through one-dimensional compression creep tests (Oliveira et al. 2012). The results show that the increasing of organic matter content leads to the increment of compression characteristics and creep characteristics. With the increasing of vertical pressure and solidification time, the compression properties of solidified soft soil are improved, the creep deformation of soft soil is reduced. In 2013, based on the idea of the fractional order can be used to reflect mechanical properties of soil, the fractional order creep model is proposed (Yin et al. 2013), and a series of creep responses for soft soil are solved. The results of comparative analysis illustrate that the mechanical properties evolution of soft soil exactly corresponds to the movement of pore water and the solid skeleton. The variable order fractional model can be used to describe the evolution of mechanical properties and the movement of pore water in the creep process of soft soil. The fractional order is related to the dissipation rate of pore water pressure. In 2014, unsaturated creep tests of weak intercalated soil in redbed soft rocks of Badong formation are carried out through using GDS triaxial apparatus (Zhu and Yu 2014; Zhu and Yu 2015), the change laws of creep characteristics for weak intercalated soil with the change of matrix suction and stress levels are studied. The results show that the creep strain has a nonlinear relationship with the change of stress and time. When the matric suction is the same, a larger deviatoric stress will lead to a larger creep strain. When the deviatoric stress is the same, a smaller matric suction will lead to a larger creep strain. Based on the Mesri creep model, an unsaturated creep model including stress-matric suction-strain time for weak intercalated soil is established. The model can be used to predict the creep behaviors of weak intercalated soil well. In 2017, in order to calculate the average rheological characteristics for inhomogeneous soil which consists of elastic-creeping material layers, a calculation method is proposed (Bobyleva and Shamaev 2017). The calculation method can be used to statistical evaluate the characteristics of composite materials. In 2018, the equivalent time line model and the cyclic strain accumulation model are combined (Cai et al. 2018), the combined method is proposed to predict the long-term settlements of soft soil subgrade under cyclic traffic loads. In 2019, the Nishihara rheological model is adopted to simulate the elasto-viscoplastic of soft soil (Zou et al. 2019), and the one-dimensional consolidation characteristics of two-layered soft soil and parameters of viscoplastic rheological model are studied. The governing equations of the coupled processes for two-layered soft soils consolidation and creep are established.

In terms of light weight soil, the shear strength characteristics of foamed particles light weight soil are studied through triaxial compression tests (Hou and Xu 2010). The results show that the cohesion and effective cohesion of light weight soil are negatively correlated with EPS particles content and positively correlated with cement content. The internal friction angle and effective internal friction angle of light weight soil are negatively correlated with EPS particles content. However, the cement content has no significant effect on the internal friction angle and the effective internal friction angle, which is between 6.0° and 13.0°. In 2011, in order to determine the influence of EPS particles size on the shear strength of light weight soil, the shear strength characteristics of mixed soil (cement mixed ratio is 12%, 20%, and EPS volume ratio is 40%) with three kinds of EPS sizes are studied through direct shear tests (Hou and Xu 2011a). The results show that the shear stress–shear displacement relationship curves of light weight soil can be divided into strain hardening and strain softening, and when the cement mixed ratio and EPS particles volume ratio are the same, the shear strength of mixed soil decreases with the increasing of EPS particles size. In engineering application, the particles size of light weight soil is recommended to be $3 \sim 5$ mm. In 2011, in order to determine the optimal moisture content of light weight soil with different mixed ratio, $\rho_{\mathrm{d}} - w$ model, $q_{\mathrm{u}} - w$ model, $RS - w$ model are proposed (Hou and Xu 2011b). The results show that light weight soil has the optimal water content, and its dry density, unconfined compression strength and specific strength increase firstly and then decrease with the increasing of water content. The correctness of the optimal moisture content model is proved by experiments. In 2012, the effects of characteristic water content on the properties of light weight soil are studied through density tests and unconfined compression strength tests (Hou 2012a). It is found that the unconfined compression strength decreases with the increasing of water content, but the strength is basically the same on the points of flow lower limit water content and flow upper limit water content, and the strength with the change of the age can be predicted by the hyperbolic model. In 2010, the creep properties of EPS particles light weight soil are studied through triaxial undrained creep tests (Gao et al. 2010a), and Singh & Mitchell model, Mesri model, Findley model are adopted to analyze creep data. It is found that all three models can be used to describe the creep properties of EPS particles light weight soil well. However, Singh & Mitchell model and Mesri model can't be used to reflect the fast rising stage of initial deformation. Based on the method of graded loading and separated loading, the comparative tests of EPS particles light weight soil are carried out through double high pressure consolidation instrument (Gao et al. 2010b). Based on the test results, the constitutive model is established. It is found that EPS particles light weight soil has attenuated creep characteristics, and there is no rapid flow stage. The creep stability time of light weight soil is positively correlated with pressure.

Some achievements have been obtained for the creep properties of light weight soil, but the creep mechanism of light weight soil hasn't been revealed throughly. The study of light weight soil creep properties in the central part of highway and railway subgrade are very rare especially. When the raw materials used are different in the tests, the creep characteristics are various greatly. In this paper, the creep properties of light weight soil made from Weihe River mud are studied by one-dimensional compression creep tests. The main influence factors of creep properties of light weight soil are obtained by analyzing test results, and then the theoretical basis is provided in practical engineering.

2 Experimental Materials and Contents

The river mud used in the tests is fetched from Yangling section of Weihe River. The river mud has a high water content and good viscosity. The colour is dark brown. The river mud contains a little small sandstone. The basic physical parameters of mud are shown in Table 1. The curing agent used in the tests is 32.5R composite Portland cement (brand: society) made by Shaanxi Society Cement Co., Ltd. The light weight material is EPS beads, its diameter is 3 ~ 5 mm, and the pure particle density is 0.0137 g/cm^3. With the mass of dry soil m_s as the standard, the other related parameters as below:

$$\text{The water content} \quad w: \quad w = \frac{m_w}{m_s} \times 100\% \tag{1}$$

$$\text{The cement content} \quad a_c: \quad a_c = \frac{m_c}{m_s} \times 100\% \tag{2}$$

$$\text{The EPS particles content} \quad a_c: \quad a_e = \frac{m_e}{m_s} \times 100\% \tag{3}$$

where m_w is the mass of water, m_c is the mass of cement, m_e is the mass of EPS particles.

According to the mixed ratio, mix the cement, water and the river mud, stir for 3 to 5 min until the mixture is homogeneous. Add the EPS particles into mixture and mix them fully. Then, the homogeneous light weight soil is filled into the mold (height: 20 mm; diameter: 79.8 mm), compact the mixed soil, and the test specimens can be got. The remolded soil samples with 22% optimum water content are prepared as the comparative tests. Firstly, the river mud is dried and crushed, and the mud is screened through a 2 mm soil sieve. Then appropriate water is added into the selected dry soil according to the water content, stir the soil until it is homogeneous. Finally, put the mixed soil into the mold at one time, and use the compaction instrument (hammer mass: 600 g; drop distance: 27.5 cm; compaction times: 35) to compact the soil until the remolded samples are obtained. The light weight soil samples with molds are put into standard curing box for 28 days, the brand of curing equipment is YH-40B, the curing temperature is 20 ± 2 °C, and the curing humidity is not less than 95%. After maintenance, put filter papers on the top and bottom of the samples, and install them in saturators. After soaking the samples for 24 h, one-dimensional compression creep tests are carried out. Some specimens in one-dimensional compression creep tests are shown in Fig. 1.

Tests scheme 1: Keep EPS particles content $a_e = 0.86\%$, water content $w = 50\%$, curing age $T = 28$d unchanged, change cement content $a_c = 15\%$, $a_c = 20\%$, $a_c = 25\%$, loads are 100, 200, 300, 400 kPa respectively, and then record the deformation of the samples at 1, 4, 9, 16, 25, 36, 64, 81, 100, 144, 225 min, and 24 h. After that, record once a day until the 30th day.

Tests scheme 2: Keep cement content $a_c = 20\%$, water content $w = 50\%$, curing age $T = 28$d unchanged, change EPS particles content $a_e = 0.31\%$, $a_e = 0.54\%$, $a_e = 0.86\%$, $a_e = 1.31\%$.

Table 1 Basic physical parameters of Weihe River mud

Natural water content w (%)	Specific gravity G_s	Natural density ρ (g/cm^3)	Plastic limit w_P (%)	Liquid limit w_L (%)	Plasticity index I_P	Liquidity index I_L	Bulk density γ (kN/m^3)	Void ratio e	Organic matter (%)
37.67	2.72	1.82	20.10	34.07	13.97	1.26	18.20	1.06	< 5

Fig. 1 Some specimens in the creep tests

Meanwhile, prepare remolded soil samples with 22% optimum water content as comparative samples, loads are 100, 200, 300, 400 kPa respectively, and then record the deformation of the samples at 1, 4, 9, 16, 25, 36, 64, 81, 100, 144, 225 min, and 24 h. After that, record once a day until the 30th day.

The method of samples fixed: put the filter papers on the top and bottom of the samples and pad the permeable stones. Fix the specimens into the consolidometers, and pour the water into the consolidometers so that the water submerged the samples about 1 cm, ensure that there is no space between the sample and the permeable stone. And then level the consolidation instrument, check the dial indicator, record the initial reading of the dial indicator, and finally add the corresponding weights (loading time must not exceed 60 s).

3 Experimental Results and Analysis

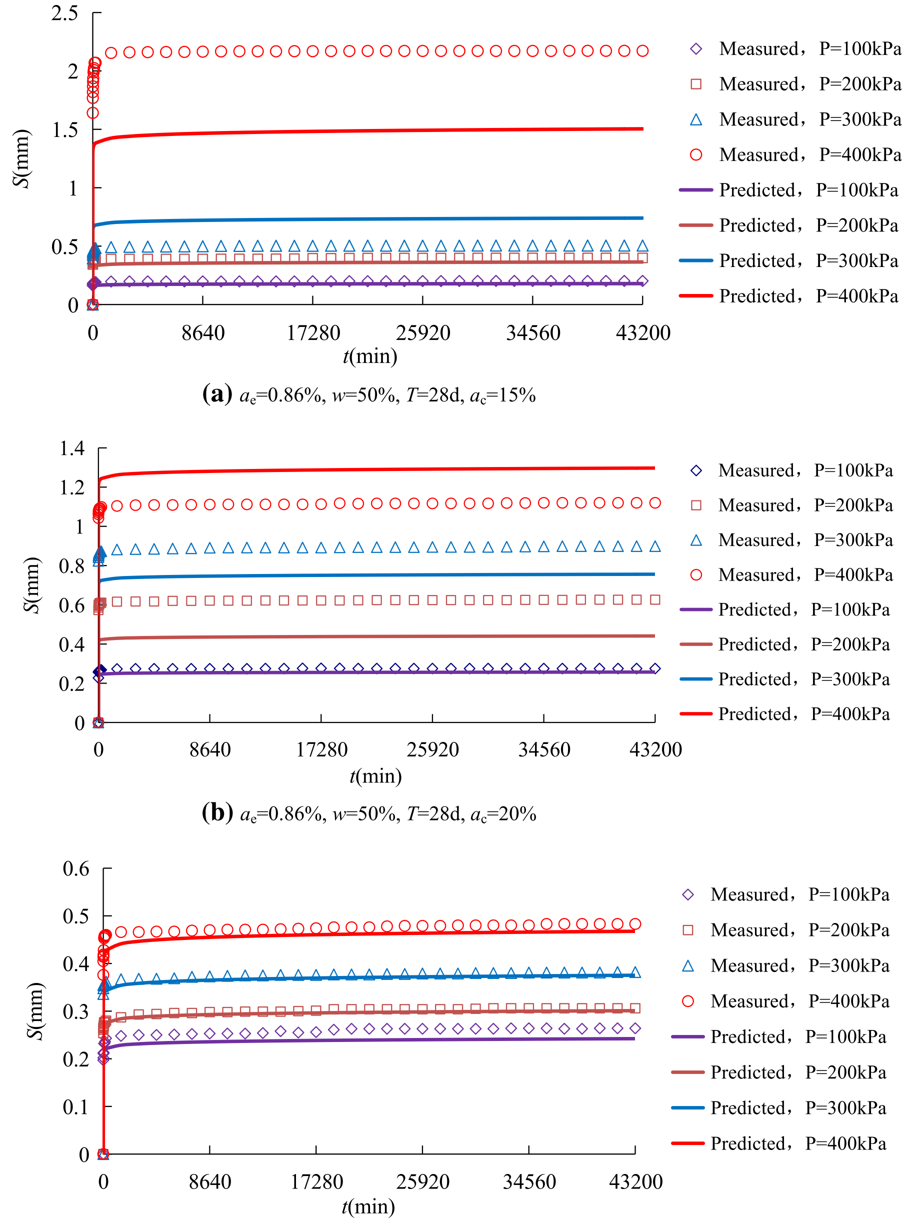
3.1 Effect of Cement Content on Creep Characteristics of Light Weight Soil

As can be seen in Fig. 2, (1) Under the different loads, the deformation curves of light weight soil samples with the same mixed ratio are "inverted L" shape. As time goes by, the creep deformation of light weight soil is increasing, and finally shows attenuated creep trend. (2) Other factors are the same, when the cement content become higher, the cementation structure strength of the samples become larger, and the creep deformation of the samples under the same loads become smaller. (3) With the deformation reaches 95% of the total deformation as the deformation stable standard, and with the increasing of the loads, the time that the deformation of light weight soil tends to be stable stage is shorter. (4) As time goes by, the deformation of the light weight soil samples gradually increases, but the deformation increment of the specimens decreases continuously. The deformation of light weight soil at 1 min accounts for 77 $\sim$ 87% of the total deformation in 30 days, the deformation at 1 h accounts for 90 $\sim$ 95% of the total deformation in 30 days, and the deformation at 1 day accounts for 95 $\sim$ 98% of the total deformation in 30 days, finally, it tends to be a stable value. It can be seen that there are no sharp creep stages for light weight soil samples, and the deformation of samples is attenuated creep.

3.2 Effect of EPS Particles Content on Creep Characteristics of Light Weight Soil

As can be seen in Figs. 3 and 4, (1) Under the different loads, the creep deformation of light weight soil samples with the same mixed ratio shows attenuated creep trend. (2) Other factors are the same, when the EPS particles content become higher, the cementation structure strength of the samples becomes weaker, and the creep deformation under the same loads becomes larger. (3) With the deformation reaches 95% of the total deformation as deformation stable standard, and with the increasing of the loads, the time that the deformation of light weight soil tends to be stable stage is shorter. (4) The deformation of the light weight soil samples at 1 min accounts for

Fig. 2 Deformation-time relation curves of light weight soil with different cement contents



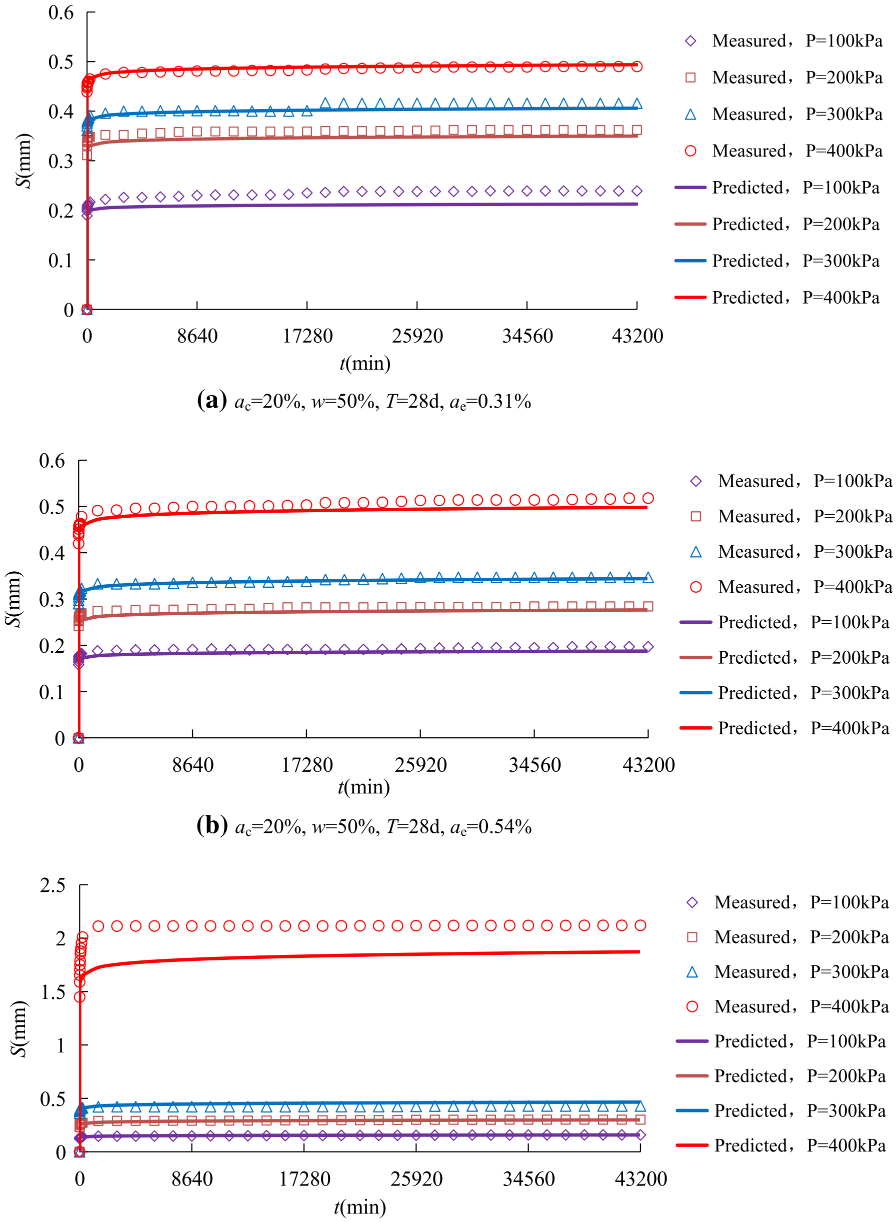
(a) a_e=0.86%, w=50%, T=28d, a_c=15%

(b) a_e=0.86%, w=50%, T=28d, a_c=20%

(c) a_e=0.86%, w=50%, T=28d, a_c=25%

77 ~ 84% of the total deformation in 30 days, the deformation at 1 h accounts for 86 ~ 92% of the total deformation in 30 days, and the deformation at 1 day accounts for 93 ~ 97% of the total deformation in 30 days, finally, it tends to be a stable value, there is no sharp creep stage for light weight soil samples. (5) The creep deformation trend of remolded soil is approximately the same as that of light weight soil, and the final deformation is attenuated creep. The deformation of remolded soil at 1 min accounts for 72 ~ 92% of the total deformation in 30 days, the deformation at 1 h accounts for 79 ~ 94% of the total deformation in 30 days, and the deformation at 1 day accounts for 85 ~ 96% of the total deformation in 30 days. It can be seen that the deformation of light weight soil is basically stable when the samples are loaded for 1 day, but the creep of remolded clay is a long process.

Fig. 3 Deformation-time relation curves of light weight soil with different EPS particles contents



(a) a_c=20%, w=50%, T=28d, a_e=0.31%

(b) a_c=20%, w=50%, T=28d, a_e=0.54%

(c) a_c=20%, w=50%, T=28d, a_e=1.31%

4 Empirical Creep Model

4.1 Establishment of Empirical Creep Model

Through regression analysis, the deformation-time equation of the specimens can be expressed as power function:

$$S = S_t t^{\beta} \tag{4}$$

In the formula: S_t, β are constants, t is the creep time, and S is the total deformation of the samples at the time t, the unit is mm. Take logarithm on both sides of the equal sign for Eq. (4), it can be obtained:

$$\ln S = \ln S_t + \beta \ln t \tag{5}$$

Let $Y = \ln S$, $X = \ln t$, $D = \ln S_t$, $B = \beta$, rewrite logarithmic equation to linear equation:

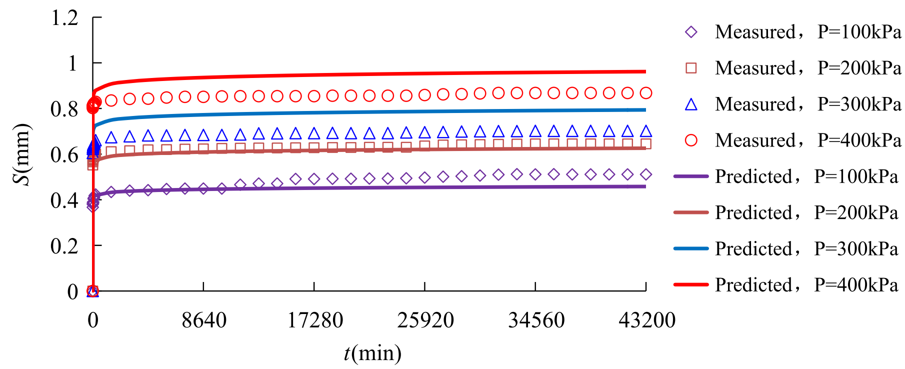


Fig. 4 Deformation-time relation curves of remolded soil (w_{op} = 22%)

$$Y = BX + D \tag{6}$$

B and D are constants, the correlation coefficient r of the rewritten linear equation is above 0.9. It proves that the deformation-time equation can be expressed as power function equation well.

According to formula (6), the formula (7) and formula (8) are obtained, and then the parameters B and D are obtained by combining formula (7) and formula (8).

$$\sum_{i=1}^{n} Y_i = nD + B\sum_{i=1}^{n} X_i \tag{7}$$

$$\sum_{i=1}^{n} Y_i X_i = D\sum_{i=1}^{n} X_i + B\sum_{i=1}^{n} X_i^2 \tag{8}$$

In the formula: n is the number of tests points. According to the obtained value of B and D, $\beta = B$, $S_t = e^D$ are obtained.

4.2 Relationship Between Model Parameters and Axial Loads

According to the test data, the value of β is calculated and is shown in Table 2. Through analyzing and comparing the value of β, it is found that the value of β for samples with same mixed ratio under different loads has little change, and can be considered as a constant. Take the average value of β under four loads as the final β value.

When the calculated data and the test data are analyzed, it is found that the value of S_t is basically equal to the value of S_1, namely, $S_t = S_1$, S_1 is the deformation of the samples at 1 min under load. There is a good exponential relationship between S_1 and P for light weight soil, but there is a good linear relationship between S_1 and P for remolded soil. The relationship of $S_1 - P$ is shown in Fig. 5. Because the deformation of samples at 1 min S_1 accounts for about 80% of the total deformation, it can be considered that the total deformation laws of the samples can be reflected by S_1. As can be seen from Fig. 5, S_1 increases approximately in exponential relationship with the increasing of P for light weight soil samples. When P=400 kPa, the deformation of light weight soil (a_e=0.86%, a_c=15% and a_c=20%, a_e =1.31%) appear substantial increase, and it deviates from the fitting line. This is because all kinds of light weight soil have a certain compression yield stress. The cement in light weight soil makes it have a certain cementation structural strength, and the EPS particles provide an elastic skeleton structure inside the samples. When the load acting on the specimen is less than the compression yield stress of light weight soil, its cementation structure may still be intact, but the deformation is mainly due to the discharge of pore water and the movement of solid particles, and therefore deformation is small. When the load is greater than the compression yield stress of light weight soil, the cementation structure might have been collapsed, there is larger deformation for the EPS particles under pressure, the deformation of the samples is mainly the plastic deformation of the EPS particles, and therefore deformation is large. When the load acting on the specimen is less than the compression yield stress of light weight soil, the cementation structure of the specimens isn't destroyed, and the main deformation is due to the discharge of pore water and the movement of solid soil particles, and the deformation is small. When the load is greater than the compression yield stress of light weight soil, the cementation structure of the samples is destroyed, there is larger deformation

Table 2 β value of the samples with different mixed ratio under different loads

Mixed ratio of the specimens	β				Average value of β
	100 kPa	200 kPa	300 kPa	400 kPa	
a_e = 0.86%, w = 50%, T = 28d, a_c = 15%	0.015	0.011	0.016	0.020	0.016
a_e = 0.86%, w = 50%, T = 28d, a_c = 20%	0.012	0.007	0.007	0.005	0.008
a_e = 0.86%, w = 50%, T = 28d, a_c = 25%	0.024	0.018	0.010	0.017	0.017
a_c = 20%, w = 50%, T = 28d, a_e = 0.31%	0.024	0.015	0.016	0.010	0.016
a_c = 20%, w = 50%, T = 28d, a_e = 0.54%	0.016	0.013	0.015	0.018	0.016
a_c = 20%, w = 50%, T = 28d, a_e = 1.31%	0.022	0.022	0.012	0.029	0.021
Remolded soil w_{op} = 22%	0.033	0.014	0.013	0.008	0.017

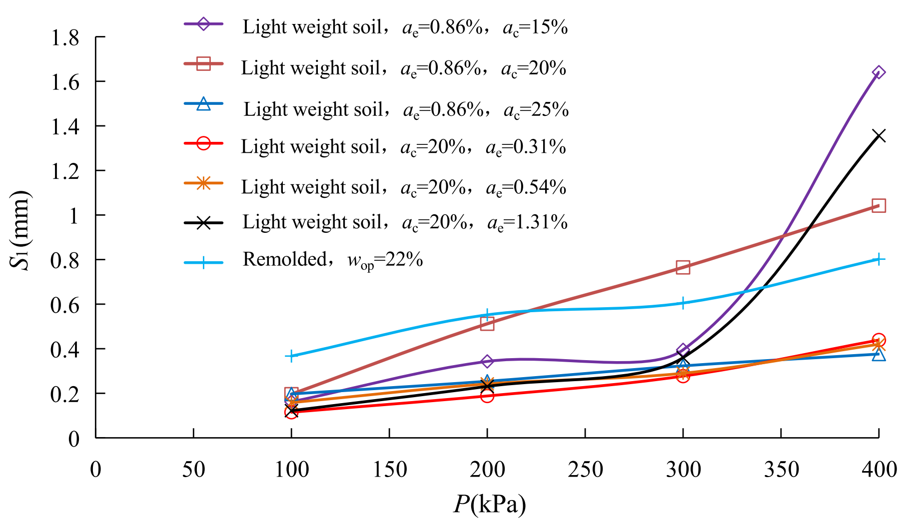


Fig. 5 Measured S_1-P relation curves of the samples with different mixed ratio

for the EPS particles under pressure, and the deformation of the samples is mainly the plastic deformation of the EPS particles. For the remolded soil samples, S_1 increases linearly with the increasing of the load, and the deformation mainly includes instantaneous settlement, principal consolidation settlement, and secondary consolidation settlement (Вялов 1987). In engineering, the load should be controlled within the compression yield stress of the light weight soil.

According to the finished $S_1 - P$ relation formula and the value of β, then substitute them into empirical creep model formula (4), and Table 3 is obtained.

4.3 Analysis and discussion of creep model prediction results

As can be seen in Figs. 2, 3 and 4, the measured points of deformation of light weight soil can fall well on the prediction curve of empirical creep model, and can clearly reflect the creep laws of light weight soil. When $P > 300$ kPa, the deformation prediction curve of the light weight soil (a_e = 0.86%, a_c = 15% and a_c = 20%, a_e = 1.31%) can't reflect the deformation-time relationship well, it indicates that the compression yield stress of the two mixed ratio of light weight soil is about 300 kPa. The measured points of deformation of remolded soil can coincide well with the deformation prediction curve of empirical creep model, and it can accurately reflect the creep laws of remolded soil. It can be seen from the above that the prediction results of the empirical creep model are satisfactory for both light weight soil and remolded soil, and the correlation coefficients between the measured point and the corresponding prediction point are all more than 0.96, which indicates that the established model has a certain reliability. However,

Table 3 Empirical creep models of light weight soil and remolded soil

Mixed ratio of the specimens	S-t empirical creep model	Mixed ratio of the specimens	S-t empirical creep model
a_e = 0.86%, w = 50%, T = 28d, a_c = 15%	$S = 0.0741e^{0.0071P}t^{0.016}$	a_c = 20%, w = 50%, T = 28d, a_e = 0.31%	$S = 0.0801e^{0.0038P}t^{0.016}$
a_e = 0.86%, w = 50%, T = 28d, a_c = 20%	$S = 0.1453e^{0.0054P}t^{0.008}$	a_c = 20%, w = 50%, T = 28d, a_e = 0.54%	$S = 0.1199e^{0.0031P}t^{0.016}$
a_e = 0.86%, w = 50%, T = 28d, a_c = 25%	$S = 0.1619e^{0.0022P}t^{0.017}$	a_c = 20%, w = 50%, T = 28d, a_e = 1.31%	$S = 0.0504e^{0.0077P}t^{0.021}$
Remolded soil w_{op} = 22%	$S = (0.0014P + 0.242)t^{0.017}$		

when $P > 300$ kPa, the deformation prediction curves of light weight soil (a_e = 0.86%, a_c = 15% and a_c = 20%, a_e = 1.31%) differ greatly from the measured points. The reason is that with the decreasing of cement content and the increasing of EPS particles content for light weight soil, the cementation structure strength of light weight soil decreases, and the compression yield stress decreases constantly. When the load is greater than the compression yield stress of light weight soil, the cementation structure might have been collapsed, the deformation increases rapidly, and the model can't be used to predict the deformation of light weight soil well. It can be seen that the empirical creep model can only be applied to the case where the load is less than the compression yield stress of light weight soil.

According to the empirical creep model in Table 3, the deformation of the specimens with different mixed ratio at different time is predicted, the predicted values are shown in Table 4. As can be seen from Table 4, (1) When other factors are the same, the deformation of light weight soil decreases with the increasing of cement content, the deformation increases with the increasing of EPS particles content, and the deformation increases with the increasing of axial load. (2) With the increasing of the time, the deformation of light weight soil increases rapidly in a short time, and then gradually increases slowly, which shows a attenuated creep trend. (3) It is assumed that with the settlement at 50 years as the total deformation, the deformation of light weight soil at 1 min accounts for 75 $\sim$ 87% of the total deformation, and the deformation of light weight soil at 1 day accounts for 86 $\sim$ 95% of the total deformation, and the deformation of light weight soil at 1 year accounts for 94 $\sim$ 97% of the total deformation. (4) It is assumed that with the settlement at 50 years as the total deformation, the deformation of remolded soil at 1 min accounts for 74% of the total deformation, and the deformation of remolded soil at 1 day accounts for 85% of the total deformation, and the deformation of remolded soil at 1 year accounts for 93% of the total deformation. (5) In short, with the 50-year settlement as the total deformation, the deformation of light weight soil can be stable in about 1 year, and the deformation of remolded soil is a long process, which needs a longer time. The reason is that light weight soil has a certain cementation structure strength. When the load is less than the compression yield stress of light weight soil, its cementation structure may still be intact, but the deformation is mainly due to the discharge of pore water and the movement of solid particles, and therefore deformation is small. When the pore water is basically discharged, the deformation is approximately stable, and the deformation is relatively small at the later stage. The deformation of remolded soil mainly includes instantaneous settlement, principal consolidation settlement and secondary consolidation settlement.When the pore water pressure dissipates thoroughly, the creep effect is formed due to soil particles movement, shear cross-motion and roll at the later stage, which leads to the large settlement of the foundation after construction.

From discussion above, it can be seen that the empirical creep model is reliable for predicting the deformation of light weight soil in a certain time scale (e.g. 50 years), and can clearly reflect the creep laws of light weight soil. However, when the creep time is infinite, the predicted deformation of light weight soil is also infinite, the result is obviously inconsistent with

Table 4 Comparison of creep deformation predicted values

Mixed ratio of the specimens	Loads (kPa)	Deformation (mm)							
		1 min	1 day	1 year	10 years	20 years	30 years	40 years	50 years
a_e = 0.86%, w = 50%,	100	0.151	0.170	0.186	0.193	0.195	0.196	0.197	0.198
T = 28d, a_c = 15%	200	0.307	0.345	0.378	0.393	0.397	0.400	0.401	0.403
	300	0.624	0.701	0.770	0.799	0.808	0.813	0.817	0.820
	400	1.268	1.424	1.566	1.625	1.643	1.653	1.661	1.667
a_e = 0.86%, w = 50%,	100	0.249	0.264	0.277	0.282	0.284	0.285	0.285	0.286
T = 28d, a_c = 20%	200	0.428	0.454	0.475	0.484	0.487	0.489	0.490	0.491
	300	0.734	0.778	0.816	0.831	0.836	0.838	0.840	0.842
	400	1.260	1.335	1.400	1.426	1.434	1.439	1.442	1.444
a_e = 0.86%, w = 50%,	100	0.202	0.255	0.252	0.262	0.266	0.267	0.269	0.270
T = 28d, a_c = 25%	200	0.251	0.290	0.314	0.327	0.331	0.333	0.335	0.336
	300	0.313	0.362	0.392	0.408	0.412	0.415	0.417	0.419
	400	0.390	0.451	0.488	0.508	0.514	0.517	0.520	0.522
a_c = 20%, w = 50%,	100	0.117	0.131	0.145	0.150	0.152	0.153	0.153	0.154
T = 28d, a_e = 0.31%	200	0.171	0.192	0.211	0.219	0.222	0.223	0.224	0.225
	300	0.250	0.281	0.309	0.321	0.324	0.327	0.328	0.329
	400	0.366	0.411	0.452	0.469	0.474	0.477	0.480	0.481
a_c = 20%, w = 50%,	100	0.163	0.183	0.202	0.209	0.212	0.213	0.214	0.215
T = 28d, a_e = 0.54%	200	0.223	0.251	0.275	0.286	0.289	0.291	0.292	0.293
	300	0.304	0.342	0.375	0.389	0.394	0.396	0.398	0.399
	400	0.414	0.465	0.512	0.531	0.537	0.540	0.543	0.545
a_c = 20%, w = 50%,	100	0.109	0.127	0.144	0.151	0.153	0.154	0.155	0.156
T = 28d, a_e = 1.31%	200	0.235	0.274	0.310	0.325	0.330	0.333	0.335	0.337
	300	0.508	0.592	0.670	0.703	0.713	0.719	0.723	0.727
	400	1.097	1.278	1.446	1.518	1.540	1.553	1.563	1.570
Remolded soil w_{op} = 22%	100	0.382	0.432	0.478	0.497	0.503	0.506	0.509	0.511
	200	0.522	0.591	0.653	0.679	0.687	0.692	0.695	0.698
	300	0.662	0.749	0.828	0.861	0.871	0.877	0.882	0.885
	400	0.802	0.908	1.003	1.043	1.056	1.063	1.068	1.072

the fact. It indicates that the empirical creep model can only be used to predict the deformation of light weight soil in a certain period of time, and the axial load acting on the light weight soil must be less than its compression yield stress. Therefore, the load should be controlled within the compression yield stress of light weight soil in practical engineering.

5 Conclusions

(1) The creep deformation of light weight soil is influenced by the cement content and the EPS particles content. When the cement content becomes higher and the EPS particles content becomes smaller, the cementation structure strength of the light weight soil becomes higher, and the creep deformation becomes smaller under the same load. For the light weight soil with the same mixed ratio, when the axial load is larger, the deformation is larger, the deformation stable time is shorter, and as time goes by, the deformation of light weight soil increases continuously, and finally tends to be a stable value. During the creep deformation of

light weight soil, there is no sharp creep stage, and the deformation is attenuated creep.

(2) The creep deformation of light weight soil is related to its compression yield stress. When the load acting on the specimen is less than the compression yield stress of light weight soil, its cementation structure may still be intact, but the deformation is mainly due to the discharge of pore water and the movement of solid particles, and therefore deformation is small. When the load is greater than the compression yield stress of light weight soil, the cementation structure might have been collapsed, there is larger deformation for the EPS particles under pressure, and the deformation increases rapidly, and therefore deformation is large. In sum, the load should be controlled within the compression yield stress of light weight soil in the practice.

(3) The empirical creep model of light weight soil in this test is expressed as power function. In a certain time scale (e.g. 50 years), the empirical creep model can be used to reflect the creep laws of light weight soil well and provide a theoretical basis for practical engineering. However, it should be noted that the model is a non-attenuated creep model and can't be used to predict deformation for too long time (e.g. infinite).

Acknowledgements Project (51509211) supported by National Natural Science Foundation of China; Project (2016M602863) supported by China Postdoctoral Science Foundation; Project (2018031) supported by Excellent Science and Technology Activities Foundation for Returned Overseas Teachers of Shaanxi Province; Project (2015SF260) supported by Social Development Foundation of Shaanxi Province; Project (2017BSHYDZZ50) supported by Postdoctoral Science Foundation of Shaanxi Province; Project (2016GY-01) supported by Yangling District Foundation; Project (2452020169) supported by the Fundamental Research Funds for the Central Universities; Project (A213021602) supported by International Cooperation Foundation of Northwest A&F University; Project (A213021803) supported by Foreign Cultural and Educational Experts Foundation of Northwest A&F University.

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