Experimental Study on Creep Characteristics of Saturated Sandy Soil with Different Fines Content

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Abstract. In order to better study and predict the post-construction settlement of sand with fine-grained blow-filled sand, sand samples with different fine-grained contents were prepared according to the actual engineering geological conditions, and one-dimensional creep tests were carried out to reveal the effect of fine-grained content on the creep characteristics of saturated sand. The results show that the creep curve of saturated sand has nonlinear characteristics and is basically divided into three stages: instantaneous deformation, rapid deformation and steady-state creep; When the content of fine grain is less than 25%, the strain is smaller than that of sand without fine grain, and the average strain is minimum when the content of fine grain is between 15%~25%; When the content of fine grain is more than 25%, the strain of sand under the same load increases with the increase of fine grain content; The 5-element generalized Kelvin model can describe the creep characteristics of saturated sand with different fine grain content, the correlation coefficient of fitting curve is 0.964~0.997, the creep parameters in the model are related to normal stress, and all the parameters increase with the increase of normal stress.

Keywords. Saturated sand, fines content, creep property, constitutive model, oedometer test.

1. Introduction

For permanent buildings built on hydraulic fill sand foundation, post-construction settlement after foundations treatment may adversely affect the safety and normal use of the buildings. The post-construction settlement of the hydraulic fill sand mainly includes the post-construction settlement of the original foundation and the hydraulic fill layer. In engineering practice, usually due to poor quality of material sources and improper control of local blow filling process, resulting in a higher content of fine particles in the sand foundation, and foundation treatment measures are difficult to control creep caused by soil weight and design load. Therefore, study the creep characteristics of the sand with fine-grained hydraulic fill sand foundation has important engineering practical value for the post-construction settlement prediction of the building.

In recent years, many researchers have studied the creep characteristics of saturated sand. Zhang Yun et al. [1-2] conducted oedometer tests to saturated sands in Shanghai and Changzhou respectively, and use the power function to fit the creep curve. Shi Xiaoqing et al. [3] analyzed the creep curve of Changzhou undisturbed sand samples, and compared the applicability of Burgers and Merchant models; Wang Fei [4] proposed to apply the Singh clay creep equation to sand Creep calculation, obtained the m value range of Singh cohesive soil creep equation in sand calculation, and it was verified by settlement calculation examples in Changzhou and Shanghai; Yang Qi et al. [5] obtained sand samples
through experiments, the relationship curve under the action of multi-level loads, using the Schiffman viscoelastic model, described the creep characteristics of the sand layer; Nian Tingkai et al. [6] described the dredging silt sand in Caofeidian Port of Tangshan A one-dimensional creep test is carried out and it is found that the Burgers body model has a higher fitting accuracy for the creep curve of dredger fill silt sand than the generalized Kelvin body model. Based on the existing research results, Wen Yanan [7] believes that there are many factors affecting sand creep, such as water content, pore pressure, stress history and path, and stress level. Wang Yanfang [8] used triaxial tests to test saturated sands. The drainage creep characteristics were studied, and it was found that the confining pressure and the relative density have a greater impact on the creep of sand. Cai Guojun [9] experimentally studied the effects of different densities, gradations, and loading methods on the creep characteristics of sand, and used a power function to fit the creep curve of sand.

For nearshore hydraulic fill sand containing fine grains, the content of fine grains in the soil should have a certain influence on its creep characteristics, and there are few reports on experimental studies in this area. In this paper, based on the land quality data of the dredging sand near the Red Sea Port in the Jizan Economic City, Saudi Arabia, oedometer test was carried out on sand with a certain fine content to reveal the influence of different fine content on creep characteristics of saturated sand. It is expected to provide a reference for the design of foundation engineering containing fine-grained dredged sandy soil.

2. Creep Test Design

According to actual engineering geological data, the percentage of fine particles $\rho$ of dredger-filled sandy soil is between 0-35%, and the relative compaction of dredger-filled sand is about 80% after the foundation treatment. In this test, remolded soil samples were used. Zhuhai sand was used as coarse-grained material, mixed with fine quartz sand to form 4 different fine-grained sand samples of 0%, 15%, 25%, and 35%. Used 80% relative compaction for creep test, and the physical properties of the sample are shown in table 1.

| $\rho$ | $\rho_r$ | $e$ | $\rho_d$ | Percentage of grain composition /% |
|---|---|---|---|---|
| | | | g/cm$^3$ | mm | mm | mm | mm | mm |
| 0 | 80 | 0.454 | 1.83 | 100 | 0 | 0 | 0 | 0 |
| 15 | 80 | 0.341 | 2.00 | 85 | 3 | 3 | 3 | 6 |
| 25 | 80 | 0.353 | 1.99 | 75 | 3.5 | 7.5 | 4.5 | 9.5 |
| 35 | 80 | 0.417 | 1.9 | 65 | 5 | 11 | 8 | 11 |

The test used single lever arm oedometer. The sample is prepared according to the set 80% relative density. A certain quality of dried sandy soil is weighed and prepared by the control density method in a standard ring knife. The diameter of the ring knife is 61.8 mm, the height is 20 mm, and the sample is saturated with water on the base of the instrument for 1 d; adopts graded loading, and the normal load $\sigma$ is divided into 50 kPa → 100 kPa → 200 kPa → 400 kPa → 600 kPa → 800 kPa; After applying each level of pressure, measure and record the change of sample height in the following time sequence: 1 min, 4 min, 9 min, 16 min, 25 min, 36 min, 49 min, 60 min, 2 h, 4 h, 6 h, 10 h, 16 h, 24 h, after 24 h, read on time every 24 h until the vertical deformation is less than 0.005 mm/d.

3. Analysis of Test Results

According to the test data, the $e \sim t$ creep curves of sands with different fine grain content under different stresses are drawn, as shown in figure 1. The test results show that the stabilization time of sandy soil with fine particle content is significantly longer than that of pure sand, and the larger the fine particle content, the longer the creep stability time; under the action of different normal stress $\sigma$, each sample The creep curve is very similar and presents nonlinear characteristics. The greater the
normal stress, the greater the initial strain. It is basically divided into three stages. The instantaneous deformation stage: short experience time and large strain rate, mainly due to the instantaneous deformation of the soil skeleton caused by; rapid deformation stage: the strain rate gradually decreases, mainly due to the large permeability coefficient of sandy soil and the rapid dissipation of excess pore water pressure; creep deformation stage: the creep curve tends to be flat, the strain rate gradually decreases and tends to close to zero, the excess pore water pressure is dissipated at this stage.

![Figure 1](image-url)

**Figure 1.** Creep curves of sands.

The relationship between the content of fine particles $\rho$ and strain $\varepsilon$ under different loads is shown in figure 2. It can be seen from figure 2 that under the same load, the content of fine particles in sandy soil has a great impact on the creep of sandy soil. When the content of fine particles is less than 25%, the strain generated by the sample under the same load is less than pure sand. If the fine-grained soil is between 15% and 25%, the average strain generated by the sample under the same load is the smallest; when the fine-grain content is greater than 25%, the greater the fine-grain content, the greater the strain generated under the same load. The reason can be understood as: when the fine particles in the sand sample are low, the fine particles exist between the pores of the coarse sand. As the content of fine particles increases, the porosity ratio of the sand decreases and the dense degree increases. The restraint effect on the deformation of the skeleton of the sand sample gradually appears, and the strain of the sand sample gradually decreases; when the fine particles are completely filled with the pores of the coarse sandy soil, the grain composition of the sandy soil at this time reaches the optimal and the strain reaches the minimum; When the fine particle content increases again, the fine particles become part of the soil skeleton and begin to share the stress. Because the strength of the fine particles is relatively low, under the action of higher stress, the strain of the sand sample will significantly increase with the increase of the content of fine particles due to the slip and break of the soil particles.
Figure 2. Fine grain content-strain.

Figure 3 shows the isochronous curves of different fine particle content, the isochronous curve of normal stress $\sigma$ and strain $\varepsilon$. The $\sigma$-$\varepsilon$ curves of different fine particle content have similar nonlinear characteristics. When the stress level is low, the curves basically overlap and the creep phenomenon is not obvious. With the increase of stress, the creep phenomenon of change is becoming more and more obvious.

Figure 3. Isochronal curves of sands.

4. Sandy Soil Creep Model
The deformation characteristics of this saturated sand creep test are very similar to the viscoelastic characteristics of the polytetrafluoroethylene membrane material in [10], so used 5-element generalized Kelvin model to fitting creep curves.

The 5-element generalized Kelvin model constitutes through two Kelvin bodies and a Hook body in series. The Hook body can reflect the instantaneous deformation, and the Kelvin body can reflect the attenuation creep. Multiple Kelvin bodies are connected in series. The initial stage of the creep curve is steep. The 5-element generalized Kelvin model model is shown in figure 4, and the one-dimensional creep equation is shown in equation (1).
In the formula: $E_H$ is the shear modulus of HOOK body, $E_{K1}$ and $E_{K2}$ are the shear modulus of Kelvin body, and, $\eta_{K1}$, $\eta_{K2}$ are the viscosity coefficient of Kelvin body.

$$
\varepsilon(t) = \frac{\sigma}{E_H} + \frac{\sigma}{E_{K1}} \left(1 - e^{-\frac{t}{\eta_{K1}}}ight) - \frac{\sigma}{E_{K2}} \left(1 - e^{-\frac{t}{\eta_{K2}}}ight)
$$

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**Figure 4.** 5 element generalized Kelvin model diagram.

Used Origin to fit the experimental data, obtained the model parameters with different fine particle contents and different normal stresses, as shown in table 2. Figure 5 shows the comparison between the calculation results of the 5-element generalized Kelvin model and the experimental data. From the data in table 2 and the calculated curve in figure 5, it can be seen that the 5-element generalized Kelvin model has good adaptability to creep data with different fine particle content, and the correlation coefficient R is 0.964~0.997. Figures 6-10 show the relationship between the 5-element generalized Kelvin creep parameters of each fine-grained sandy soil sample and the normal stress. It can be seen from the figure that the five parameters basically increase with the normal stress. As for the increasing trend, its correlation needs to be further studied.

**Figure 5.** Comparison of calculation results of 5-element generalized Kelvin model with experimental data.
Table 2. Parameter inversion values of 5-elements generalized Kelvin model.

| ρ   | σ    | $E_{K1}$ | $E_{K2}$ | $\eta_{K1}$ | $\eta_{K2}$ | $E_{H}$ | R  |
|-----|------|----------|----------|--------------|--------------|----------|----|
|     | /kPa | /MPa    | /MPa    | /MPa·min     | /MPa·min     | /MPa    |    |
| 50  | 12   | 9.1     | 44.6    | 7560.3       | 5            | 0.992   |    |
| 100 | 39.1 | 71.8    | 46.9    | 10775.9      | 5.9          | 0.966   |    |
| 200 | 128.2| 2832.4  | 79.4    | 93075.9      | 7.3          | 0.989   |    |
| 400 | 231.2| 1675.8  | 140.8   | 89743.5      | 11.3         | 0.993   |    |
| 600 | 337.1| 4035.6  | 205.5   | 136061.7     | 14.5         | 0.984   |    |
| 800 | 442  | 5253.7  | 233.9   | 201469       | 17.2         | 0.982   |    |
| 5   | 17.9 | 58.3    | 25.4    | 54747.7      | 5.1          | 0.964   |    |
| 100 | 32.4 | 328.8   | 28.3    | 53444.3      | 7.3          | 0.973   |    |
| 200 | 105.8| 2281.6  | 56.5    | 107812.2     | 9            | 0.997   |    |
| 400 | 256.4| 3784.8  | 137     | 164527.3     | 13.7         | 0.99    |    |
| 600 | 363.6| 5655.3  | 229.9   | 294715.4     | 17.9         | 0.994   |    |
| 800 | 615.4| 12791   | 266.7   | 526627       | 21.3         | 0.996   |    |
| 5   | 17.4 | 74.4    | 16      | 14135.7      | 5.8          | 0.987   |    |
| 100 | 25.2 | 149.5   | 20.7    | 18333        | 8.6          | 0.981   |    |
| 200 | 71.2 | 710.2   | 68.3    | 45358.1      | 9.2          | 0.978   |    |
| 400 | 130.7| 1257.7  | 120.8   | 67163        | 13.3         | 0.988   |    |
| 600 | 204.1| 2240.8  | 161.3   | 107081.3     | 16.8         | 0.989   |    |
| 800 | 310.1| 4327.9  | 215.6   | 217165.4     | 19.6         | 0.989   |    |
| 5   | 10.4 | 36.4    | 6.8     | 6423         | 1.9          | 0.994   |    |
| 100 | 12.9 | 53.6    | 9.5     | 8842.5       | 3.3          | 0.991   |    |
| 200 | 44.8 | 615.1   | 33.9    | 35615.1      | 4            | 0.989   |    |
| 400 | 73.1 | 1425    | 66.7    | 106499.6     | 6.2          | 0.989   |    |
| 600 | 108.1| 2715.3  | 104.5   | 205430.4     | 8.2          | 0.986   |    |
| 800 | 172.4| 7311.2  | 144.9   | 355082.3     | 9.9          | 0.993   |    |

Figure 6. Change value of creep parameter $E_{H}$ with normal stress.
Figure 7. Change value of creep parameter $E_{K1}$ with normal stress.

Figure 8. Change value of creep parameter $E_{K2}$ with normal stress.

Figure 9. Change value of creep parameter $\eta_{K1}$ with normal stress.

Figure 10. Change value of creep parameter $\eta_{K2}$ with normal stress.

5. Conclusion
Through indoor uniaxial compression tests, studied the creep characteristics of saturated sand samples with different fine particle contents, and the results showed that:

1) Saturated sandy soil with different fine grain content have certain creep characteristics. The creep curve presents nonlinear characteristics and is basically divided into three stages: instantaneous deformation, rapid deformation and creep deformation.

2) Under the same load, the content of fine particles in sand has a greater impact on sand creep. When the fine particle content is less than 25%, the strain generated by the sample under the same level of load is less than pure sand, and the sand sample is between 15% and 25% of the fine particle content, and the sample is in the same stress level the average strain generated under load is the smallest; when the content of fine particles is greater than 25%, the greater the content of fine particles, the greater the strain generated by the sample under the same stress level.

3) The 5-element generalized Kelvin model can well describe the creep characteristics of saturated sands with different fine-grained content. The correlation coefficient of the fitting curve is 0.964–0.997. the five parameters basically show an increasing trend with the increase of normal stress.
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