IOP Conference Series: Earth and Environmental Science

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IOP Conf. Series: Earth and Environmental Science 218 (2019) 012011 doi:10.1088/1755-1315/218/1/012011

Experimental Study of Stress-stain Relationships of Frozen Sand

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Abstract. The MTS-Landmark 370.10 test system is used to carry out low temperature conventional triaxial tests on frozen sand at a temperature of -7 ° C and the confining pressures of 0.1, 0.5, 1, 4, and 8 MPa. The test results show that the deviation stress-axial strain relationship curves of frozen sand are strain softening type, which can be divided into three stages: linear, nonlinear and strain softening. The modified Duncan–Chang model proposed by Lai et al. is used to describe the constitutive relation of frozen sand. The fitting results show that the model has good applicability and high fitting precision.

1. Introduction

Frozen sand is a type of frozen soil material which takes sand as its soil skeleton and contains a high proportion of gravel and particles of large size. Many achievements have been made in the study of mechanical properties of frozen sand. Sun et al. studied the effect of water content on the uniaxial compressive strength of frozen sand, and found that the uniaxial compressive strength of the sample decreased with the increase of water content[1]; Lai et al. studied the effect of supersaturated water content and temperature on the strength of frozen sand by freezing low temperature triaxial test[2]; Based on the results of conventional triaxial test of frozen sand, Ma et al. found that the shear strength of frozen sand increased with the increase of confining pressure, and after the confining pressure exceeds a certain value, it gradually decreases with the increase of confining pressure[3]; Jin et al. analyzed the damage characteristics of frozen sand under conventional triaxial test conditions[4].

The reliability of the numerical calculation results of geotechnical engineering is closely related to the soil constitutive model selected in the calculation, and accurately describing the stress-strain relationship of the soil is an important issue of the constitutive model[5]. The nonlinear model has been widely used in geotechnical engineering, because its parameters are relatively easy to determine and it is more convenient to apply in numerical calculation. The Duncan-Chang hyperbolic model[6] is the most widely used nonlinear model, but the model uses a hyperbolic curve to describe the bias stress-axial strain relationship, which cannot describe the softening phenomenon of the soil. It is found that the residual sand stress-axial strain curve is softened and can be divided into three stages through a series of triaxial tests of frozen sand. Therefore, in order to better reflect the softening characteristics of the deviating stress-axial strain of frozen sand, the improved Duncan-Chang model proposed by Lai et al.[7] is used to describe the stress-strain relationship of frozen sand.

2. Test conditions

A series of three axis tests on frozen sand are carried out by the MTS-Landmark 370.10 test system of Sichuan Agricultural University. The temperature condition of the test is -7 °C, and the confining pressure conditions are 0.1 MPa, 0.5 MPa, 1 MPa, 4 MPa and 8 MPa. The frozen sand sample is prepared by referring to the method of Liu et al.[8]. The dry density of the sand used for the test is 1.75 g/cm^3, and the moisture content of the sample is 20 %. The particle composition is shown in Table 1.

Table 1. Test soil particle grading table

Particle size (mm)	<0.075	<0.25	<0.5	<1	<2	<5	<10
The content less than a particle size (%)	8	33	58	76	81	92	100

3. Test results

As can be seen from fig. 1, under the action of the load, the variation of the deviated stress with the axial strain can be roughly divided into three stages: (1)the linear stage, in this stage, the frozen moraine soil samples have good integrity and initial stiffness at the early loading stage. The stress-strain curve changes linearly When the axial strain is small (about 1%); (2)The nonlinear stage, in this stage, the stress-strain curve no longer maintains a linear relationship, but the stress keeps increasing and the stress shows a deceleration and upward trend before the stress peak occurs; (3)the strain softening stage, in this stage, the stress decreases with increasing axial strain when the axial strain continues to increase from the peak intensity corresponding strain.

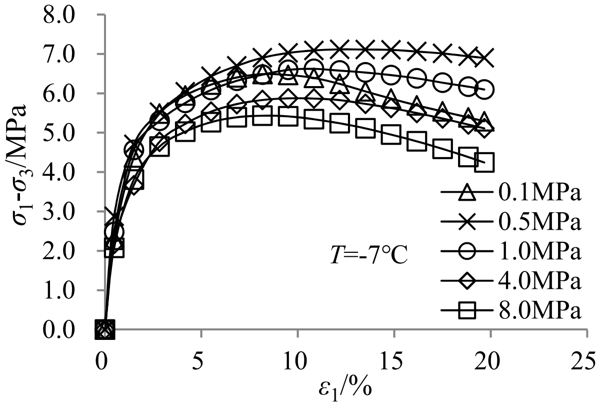


Figure 1. Stress-strain curves of frozen sand under various confining pressures at -7℃

4. Nonlinear constitutive model

4.1Stress-strain relationship

It can be seen from Fig. 1 that the deviation stress-axial strain curve of the frozen sand has obvious softening characteristics. In order to describe the strain-softening phenomenon of frozen sand, Lai et al. proposed a modified Duncan-Chang model. The model can be expressed as follows:

$$\sigma_1 - \sigma_3 = \frac{\varepsilon_1}{a\varepsilon_1^{\,2} + b\varepsilon_1 + c} \quad (1)$$

where σ_1 and σ_3 are axial stress and confining pressure respectively; ε_1 is axial strain; a, b and c are material parameters, and according to the frozen sand test data, the parameter expression is corrected as follows:

$$\left.\begin{aligned} a &= 100/\left(E_0\varepsilon_m{}^2\right) \\ b &= 1/\left(\sigma_1-\sigma_3\right)_m - 200/\left(\varepsilon_m E_0\right) \\ c &= 100/E_0 \end{aligned}\right\} \tag{2}$$

where $(\sigma_1\text{-}\sigma_3)_m$ is the maximum deviation stress value, ε_m is the axial strain corresponding to the maximum deviation stress value. The physical meaning of the parameters is shown in Fig. 2.

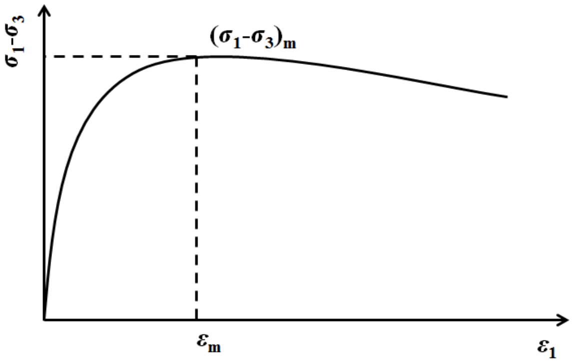


Figure 2. The sketch of the physical meaning of the model

According to the definition of the tangent modulus E_t and by differentiating (1), the following can be obtained:

$$E_t = \frac{d(\sigma 1-\sigma 3)}{d\varepsilon_1} = \frac{-a\varepsilon_1{}^2}{\left(a\varepsilon_1{}^2+b\varepsilon_1+c\right)^2} \tag{3}$$

According to the definition of initial tangent modulus, we can obtain the expression as bellows:

$$E_0 = \left(100\frac{d\left(\sigma_1-\sigma_3\right)}{d\varepsilon_1}\right)_{\varepsilon_1=0} = \frac{100}{c} \tag{4}$$

Based on the test data and according to the (4), the relationship between the initial tangential modulus E_0 and the confining pressure σ_3 is obtained, as shown in Fig. 3. It can be seen from Fig. 3 that as the confining pressure increases, the initial tangential modulus increases, but the growth rate decreases. This is because as the confining pressure increases, the frozen soil becomes denser under the action of pressure, thereby increasing the initial tangential modulus. And with the further increase of the confining pressure, the ice medium in the frozen sand is crushed and melted, resulting in a decrease in the initial tangential modulus. The relationship between initial tangent modulus E_0 and the confining pressure σ_3 can be expressed as follows:

$$E_0 = \frac{\left(\sigma_3/p_a\right)}{0.0005+0.0015\left(\sigma_3/p_a\right)} \tag{5}$$

where p_a is the standard atmospheric pressure.

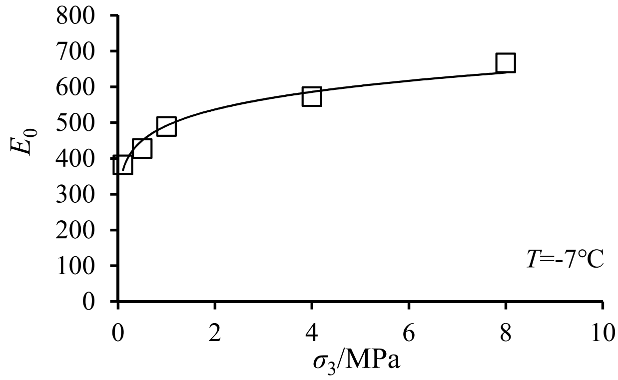


Figure 3. Relationship between the initial tangent modulus and the confining pressure

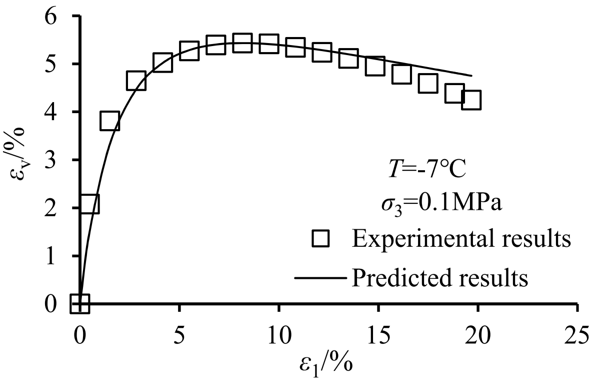
4.2Parameter Determination

The stress-strain relationship of the improved Duncan–Chang model contains three parameters, *a*, *b* and *c*. Based on the experimental data, the parameters *a*, *b* and *c* can all be calculated by (2). The parameter values determined in this paper are shown in Table 2.

Table 2. Parameters table

T/℃	σ_3/MPa	*a*	*b*	*c*
-7	0.1	0.0061	0.0979	0.2618
	0.5	0.0036	0.1114	0.2339
	1.0	0.0043	0.0934	0.2045
	4.0	0.0019	0.1157	0.1746
	8.0	0.0009	0.1186	0.1499

In order to verify the applicability of the model, the predicted values of the model are compared with the experimental results. Due to space limitations, only the comparison results under the confining conditions of 0.1 MPa, 1 MPa and 8 MPa are shown, as shown in Fig. 4. It can be seen from Fig. 4 that the predicted values of the model agree well with the experimental results.



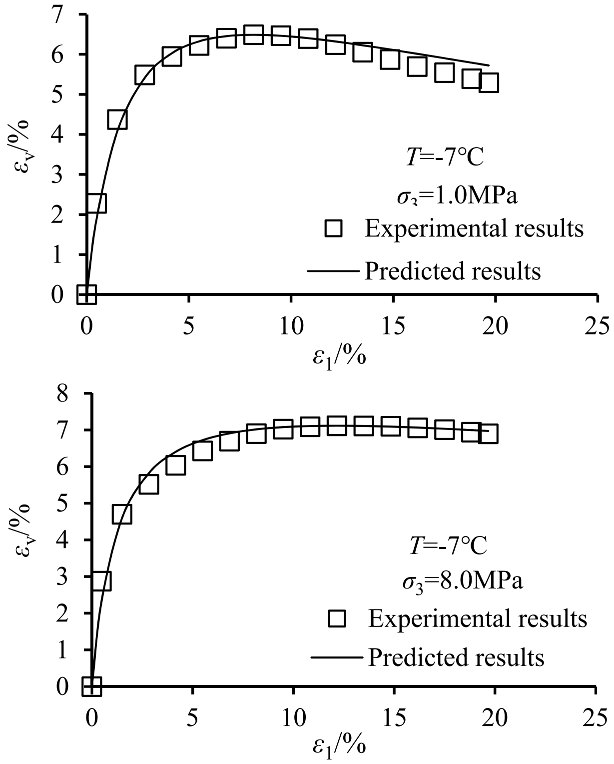


Figure 4. Comparisons between test data and predicted results of deviatoric stress-axial strain

5. Conclusions

A series of triaxial tests for frozen sand with confining pressure 0.1 MPa, 0.5 MPa, 1 MPa, 4 MPa and 8 MPa have been performed at temperature -6 ℃ in this study, Based on the test results, the model proposed by Lai et al. are used to describe the stress-strain relationship of frozen sand. Some conclusions are made as follows:

(1)The strained softening phenomenon occurs in the frozen sand during the triaxial shearing process. The deviation stress-axial strain curve can be divided into three stages: linear, nonlinear and strain softening.

(2)The improved Duncan–Chang model proposed by Lai et al. is used to describe the stress-strain relationship of frozen sand. The predicted results of the model are compared with the experimental results, and the results show that the model have good applicability to frozen sand and can better describe the stress-strain relationship of frozen sand.

Acknowledgments

This work was supported by the Student's Platform for Innovation and Entrepreneurs (04070055 and 04054662), and National Natural Science Foundation of China (41701063 and 41672304).

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