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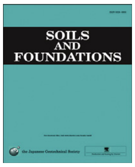

A one-dimensional creep model for frozen soils taking temperature as an independent variable

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Abstract

In this paper, a one-dimensional creep model that takes temperature as an independent variable was proposed for frozen soils. A series of K_0 compression tests was conducted under different constant surcharge loads with stepped increases in temperature. An analysis of the test results indicated that the characteristics of creep strain, developing due to the stepped increases in temperature, matched well with the parallel lines postulate of the isotache model for unfrozen soils. The independent variable (stress) in the original model was replaced with a reciprocal of the temperature's absolute value, and a novel model for directly describing the effect of the increase in temperature on the creep behavior of frozen soils was established. It was verified by the test results in this study and in previous research work that the tendency of the stepped development of creep strain, due to the stepped increases in temperature, can be reasonably captured by the model. Based on further analysis of the test results, a simplified parameter-obtaining method was recommended and its applicability was verified.

Keywords: Frozen soils; Creep model; Temperature; Independent variable

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1. Introduction

Over the past few decades, a rise in the large-scale ground temperature, characterized by permafrost degradation, has been observed in cold regions (Li and Cheng, 1999; Yu et al., 2013). Due to this rise in ground temperature, warmer permafrost layers have often formed and led to considerable creep settlement in the layers (Qi et al., 2007; Ma et al., 2008). In certain areas of cold regions, where the deformations of infrastructure foundations need to be strictly controlled, such as along high-grade highways and high-speed railways, the creep of the permafrost layers must be taken into consideration. Therefore, in the design of permafrost foundations and for the prevention of engineering damage, the making of precise predictions of the creep of frozen soils has become an urgent task.

To get a good understanding of the creep behavior of frozen soils, tremendous experimental work has been carried out (Fish, 1980; Ladanyi, 1983; Zhu and Carbee, 1983; Vyalov, 1986). Based on their test results, some empirical models have been proposed to predict creep at different stages (i.e., primary, secondary and tertiary stages) (Goughnour and Andersland, 1968; Ladanyi, 1972; Ting and Martin, 1979; Zhu and Carbee, 1983), where the effects of the stress level, the ice content, the temperature and the long-term strength are taken into account. These empirical models were established under certain testing conditions which reduce their engineering applicability. This situation certainly does not help the application of modern simulation strategies in cold regions. Therefore,

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theoretical models have been proposed for more general stress states. Viscoelastoplastic models were deduced to describe the changes in microscopic damage during creep based on thermodynamics and damage mechanics (Miao et al., 1995; He et al., 1999). By combining the parabolic yield criteria, plastic flow rules and the long-term strength of frozen soils and mechanical elements, elemental rheology models were proposed to describe the creep behavior during different creep stages (Yang et al., 2010; Li et al., 2011; Wang et al., 2014; Liao et al., 2016). Zhou et al. (2016) extended the hyperplasticity theory with parabola-shaped strength loci to describe the rate-dependent behavior of frozen loess. Based on an extended hypoplastic model (Xu et al., 2016a), Xu et al. (2016b) decomposed the strain of frozen soils into ‘solid’ and ‘fluid’ components, and developed a rate-dependent model for frozen soils with the second time derivative of strain.

In these previous modeling works, the focus was mainly placed on describing the effects of the stress states on the creep behavior of frozen soils under certain temperatures, i.e., stress is taken as an independent variable, while some parameters were related to temperature so as to describe the influence of temperature. When these models were applied to engineering problems, a series of mechanical tests was carried out to obtain the parameters at different temperatures, and the relationships between the model parameters and the temperature were established through data fitting (Wang et al., 2014). This is an indirect and approximated method for reflecting the effect of temperature and may reduce the calculation accuracy to some extent. In some practical engineering problems, the underground stress at a certain layer is usually constant, while the ground temperature increases continuously due to global warming and the thermal disturbance of infrastructures in permafrost regions, such as the Qinghai-Tibet Highway and Railway (Qi et al., 2007; Qin et al., 2009). It is tedious work to calculate the creep settlement under such conditions, for the model parameters under different temperatures must firstly be independently determined. To directly investigate the effect of the increasing temperature on the creep behavior of frozen soils, Qi and Zhang (2008) conducted a series of K_0 temperature step-increase tests under different constant surcharge loads. It was indicated that with the stepped increases in temperature, a similar tendency is seen in the change in creep strain as it is applied with surcharge loads. In other words, the rise in temperature plays a role equivalent to that when the increase in stress acts on the stress-strain curves. Considering the phenomenological effects of temperature on the development of creep strain, it can also be taken as an independent variable. For unfrozen soils, a large number of models have been proposed based on the results of stress-strain tests, such as the Modified Cam-Clay and isotache creep models (Roscoe and Burland, 1968; Den Haan, 1996; Yin and Wang, 2012). Therefore, it would surely be worthwhile to try establishing a model taking temperature as an independent variable to directly describe the influence of the increase in temperature on the creep behavior of frozen soils.

In this paper, a series of temperature step-increase K_0 compression tests is carried out on a Chinese standard sand under different constant surcharge loads. The test results are analyzed to obtain the characteristics of the developing creep strain. Based on an analysis of the test results, a creep model is proposed, taking temperature as an independent variable, and the applicability is verified with the test results of both this study and the previous research work.

2. Testing procedure

A Chinese standard sand was taken as the study object. The grain size distribution curve for this sand is shown in Fig. 1. Sand samples were prepared with the multiple sieving pluviation (MSP) method (Miura and Toki, 1982; Baker and Konrad, 1985). As is shown in Fig. 2, with the MSP method, the dry unit weight of the samples was controlled by the falling height of the sand particles passing through the sieves. In this study, eleven sieves were used and the height of each was 3 cm; thus, the total falling height was 33 cm. The samples were formed to have the dimensions of 125.0 mm in height and 61.8 mm in diameter within a steel tube (Fig. 2). Then, the samples were fixed, together with the steel tube, onto two sides with porous stones and a steel frame, and saturated with distilled water by vacuum. The saturated samples were then placed into a container full of distilled water and put in a refrigerator for quick freezing, so that the water in the samples would be frozen in its original position and the ice would be distributed evenly in the sample (Ma et al., 2015). Four samples were prepared according to the above method. The dry unit weight, the water content and the degree of saturation of each sample are listed in Table 1.

All the K_0 temperature step-increase tests were conducted on a multifunction environmental testing apparatus (Fig. 3) with the controlling accuracy of the displacement and stress of 0.001 mm and 1 kPa, respectively. Details on the apparatus can be found in literature (Yao et al.,

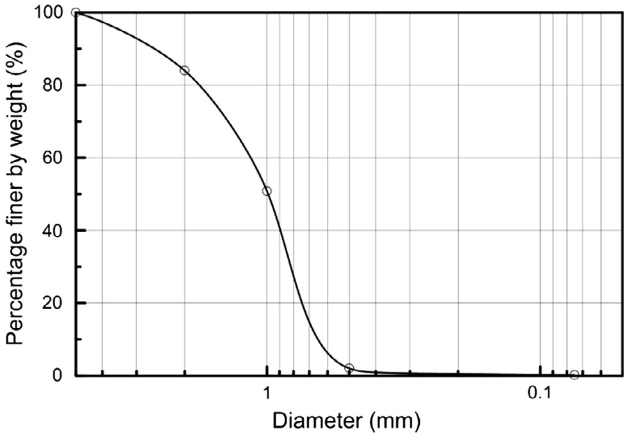

Fig. 1. Grain size distribution curve for the Chinese standard sand.

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