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An experimental study of the heat generated during cyclic compressive loading of frozen soils

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A B S T R A C T

Based on the results from a series of testing with temperature monitored, using embedded thermistor temperature sensor in frozen specimen during cyclic compressive loading, it is known that, when the environmental temperature surrounding the specimen keeps constant, the temperature in the frozen specimen increases with the time of load lasted, and the temperature rise keeps getting bigger with increasing stress amplitude, load frequency and coarse particle content included in the specimen; whereas it is basically unchanged when the water content is beyond the saturated value at −0.5 °C. Additionally, the results also show that in a given time range, along the radial direction of the specimen the temperature distribution is basically uniform, and along the axial one there is slight difference, not beyond 0.05 °C; when the time is beyond the given one, the temperature rise, on the same cross-section of the specimen, is much obvious for the central point than for any other point.

1. Introduction

Frozen soil is made up of solid mineral particles, ice inclusions, liquid water (unfrozen water and tightly bound water) and gaseous inclusions (water vapor and air) (Tsytovich, 1985). It distinguishes itself from other geotechnical engineering materials due to the existence of ground ice. Physical and mechanical properties of the frozen ground are highly variable and extremely sensitive to changes in soil temperature (Zhou et al., 2000). Based on the literatures of mechanics feature on frozen soils, they are approximately sorted into two categories: on the one hand, the mechanics property of frozen soils is discussed when the initial temperature of specimen (that is test temperature) changes and the other testing conditions are fixed (see e.g., Tsytovich and Sumgin, 1937 Francis and David, 1981; Wu and Ma, 1994; Zhu, 1987; Zhang et al., 2007; Zhao et al., 2006). On the other hand, under condition of the fixed initial temperature of specimen, the influence of the soil type, the initial dry density and water content of specimen, load type, et al. on the mechanics feature are analyzed (see e.g., Francis and David, 1981; Gardner et al., 1984; Li et al., 2004; Yang et al., 2010).

In all the aforementioned literatures, the specimens are in constant negative temperature environment in the course of testing, thus the temperature change in the specimens is not been generally considered during loading. Based on the studying results on metal and polymeric materials, it is known that under the simple tension or compression, a large part of the mechanical energy converts into heat, which causes the temperature rise of materials (Dillon, 1966, 1976; Rittel, 1999, 2000). As far as polymeric materials are concerned, the effect of hysteretic heating has been clearly shown to dramatically affect the mechanical response of the material (Constable et al., 1970; Riddell et al., 1966). Frozen soils, as a material with high sensibility to temperature, when the heat is not allowed to fully flow out of the structure during compressive load, its temperature or unfrozen water content will change, and thus its mechanical property will be changed. The study from Parameswaraj (1985) shows that the temperature of frozen sand rises from −3.5 °C to −2.5 °C during cyclic loading; Zhang and Zhu (1999)also reported that, in truth, the internal temperature of frozen specimen gradually increases when the confining pressure or cyclic loading with high frequency or high stress amplitude is applied to it, or when it is subjected to rapid strength testing. In recent years, some simply results are also described by Zhang et al. (2006, 2008). Except for the four relative literatures above, the further relevant work cannot be found. The objective of the present research is to experimentally determine the temperature rise of cylindrical frozen samples during cyclic loading, and discuss the factors affecting the temperature change.

2. Experiments

2.1. Testing materials and conditions

2.1.1. Sample preparation

In this study, the soil used was silty sand and silty clay taken from Qinghai–Tibet Railway constructions' site and clay from Qinhai

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Table 1
The basic physical properties of tested soils.

Composition of grains/%					Liquid	Plastic	Soil type
2–0.5 /mm	0.5–0.25 /mm	0.25–0.075 /mm	0.075–0.005 /mm	<0.005 /mm	Limit /%	Limit /%	
1.85	8.03	47.44	36.57	6.03	/	/	Silty sand
/	/	5.64	60.22	34.14	32.88	17.50	Silty clay
/	0.26	21.2	65.60	12.94	37.8	17.7	Clay

Table 2
Water content and dry density.

Water content (%)	15.0	20.17	40.0	60.0	80.0	Silty sand
Dry density (g/cm^3)	1.80	1.66	1.12	0.82	0.76	
Water content (%)	15.23	20.64	40.0	60.0	80.0	Silty clay
Dry density (g/cm^3)	1.80	1.66	1.16	0.88	0.77	
Water content (%)	15.0	/	/	/	/	Clay
Dry density (g/cm^3)	1.80	/	/	/	/	

Jiangcang, which has been used as subgrade material and foundation soil in the process of building railway and roadway in cold regions. Their physical parameters were listed in Table 1. The procedure of preparing samples is performed according to the Specification of Soil Test (GB/T50123-1999) issued by the Ministry of Water Resources, PRC. All the specimens, 125.0 mm in height and 61.8 mm in diameter, were compacted in four layers, with water content and corresponding dry density listed in Table 2. Then the samples with mold were frozen in a refrigerator at −20.0 °C for over 24 h, and afterwards the molds were removed, and the samples were covered with rubber sleeve and placed in an incubator at the test temperature for over 12 h so that the sample had a uniform temperature. It is noticed that at the same test temperature, the initial temperature difference between specimens was less than 0.1 °C, and the difference between cross-sections in each specimen was not beyond 0.05 °C before the test was conducted.

2.1.2. Testing condition

All the specimens were loaded in compression by a prescribed sinusoidal load at different conditions using a machine-MTS 810, which is installed inside a room at constant normal temperature, the environment temperature of specimen is controlled by a combination of a constant temperature cycle device and a specially designed thermotank, shown in Fig. 1. The thermotank structure is described in the invention patent (Chang et al., 2001). The testing specimen is placed at the centre of the thermotank, the end plates are glass steel with similarity in strength and anti-deformation to frozen soils, and have good heat-insulation property. A slight pressure (the minimum sinusoidal load) was applied to ensure sustained contact with the specimen. The maximum sinusoidal load was chosen according to the static strength (F) of the specimen. The static strength, at a shear rate of 5.0 mm/min, is the peak value on the stress–strain curve or the stress value at 20% strain when no peak value appears on the stress–strain curve.

All of the tests were stopped when they were continued for about 1000–1200 s, and corresponding total strain of the specimens ranged from 2.0 to 10.0%. The data were collected by computer continually.

2.2. Thermistor temperature sensor of measuring temperature

In the researches of metal and polymeric materials, the temperature variations throughout the test were monitored by means of a small embedded (T-type) thermocouple Rittel (1998) or infrared sensing (Craig et al., 1994). The thermocouple can be embedded in the specimen with a small size and free from temperature change itself during compressive loading, the infrared sensing is only used to measure the surface temperature of materials, and the measuring error of both the techniques is in the range of 1.0–2.0 °C. Obviously, they both are not suitable for measuring the temperature change of frozen soils. As a result, a new type of thermistor temperature sensor (see Fig. 2, the size can be made according to customer requests) is introduced. It is developed and made in our laboratory, more details are described by Liu et al. (in press). In this paper, the diameter and length of the temperature sensor are 2.0 mm and 35.0 mm(10.0 mm exposed metal and 25.0 mm insulated metal), respectively, and the length of lead wire is 1.5 m, the bearing capacity is not beyond 10.0 MPa.

For ensuring a close contact of the thermistor temperature sensor with the specimen, three small holes were first drilled at three given corresponding points on the sample mold, and the temperature sensors were then inserted through the holes and directly embedded in the specimen, respectively during the specimen was prepared (Fig. 3).

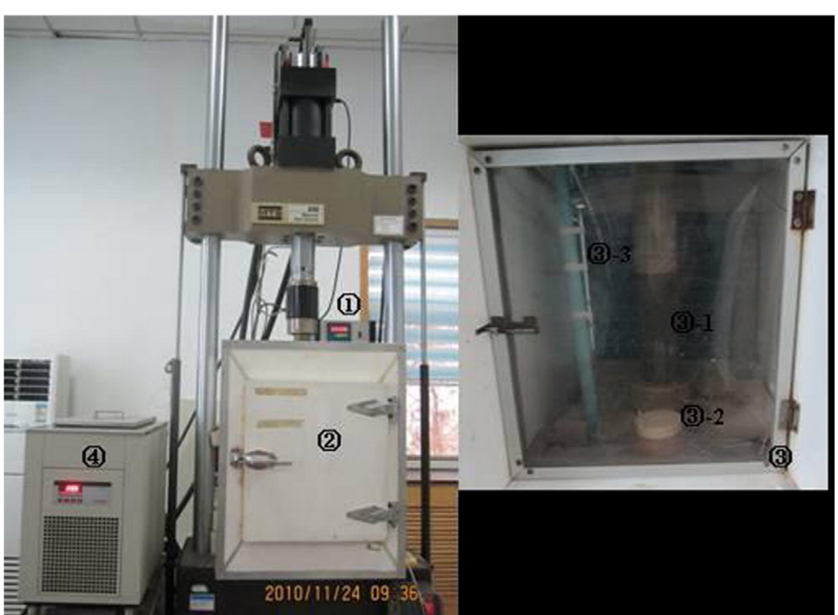

Fig. 1. Schematic diagram of the set up showing the sample and the machine ①-temperature controller; ②-thermotank; ③-inner of thermotank; ③-1-sample; ③-2-end plate; ③-3- thermistor temperature sensor; ④-cooling bath.