Cold Regions Science and Technology 58 (2009) 136–142

Contents lists available at ScienceDirect

Cold Regions Science and Technology

journal homepage: www.elsevier.com/locate/coldregions

Ultrasonic technique as tool for determining physical and mechanical properties of frozen soils

Martin Christ *, Jun-Boum Park

Department of Civil & Environmental Engineering, Seoul National University, 151-742, Republic of Korea

ARTICLE INFO

Article history:
Received 19 February 2009
Accepted 18 May 2009

Keywords:
Frozen soil
Unfrozen water content
Ultrasonic velocity
Dynamic elastic modulus
Dynamic shear modulus
Poisson's ratio

ABSTRACT

Ultrasonic velocities of compressional and shear waves in frozen sand, silty-sand and silt were measured at subfreezing temperature and the relationship between acoustic and physical-mechanical properties examined. Ultrasonic measurements revealed that the influence of temperature on ultrasonic velocities is due to the phase transition from water to ice. Different methods were proposed to determine the amount of unfrozen water in frozen soils. The unfrozen water content was measured directly by time domain reflectometry and compared to predicted values using different theoretical approaches. The prediction models showed good agreements with measured values at low temperatures. However, the shape of the curves obtained did not completely satisfying as the estimated unfrozen water fraction near 0 °C was significantly greater than the measured values. Finally, based on the elastic wave theory and measured acoustic velocities the elastic constants of the frozen soils were calculated. The changes in elastic constants were found to be related to the increase in ice content, ice stiffness by ice cementation and a decrease in unfrozen water content.

© 2009 Elsevier B.V. All rights reserved.

1. Introduction

Frozen soils are a multiphase system that includes soil particles, ice, unfrozen water and gases. The frozen soil behavior in response to engineering works is strongly dependent on the composition of these phases. Temperature and water are the variables that have the greatest influence on physical-mechanical properties such as strength (Andersland and Ladanyi, 1994). This is because, the phase change from water to ice increases the strength of the soil by ice cementation of soil particles. The lower the temperature the more ice will form and the stronger the soil. However, even at subfreezing temperatures, some water in the pores remains unfrozen, influencing the mechanical strength indirectly by reducing the ice content. The existence of unfrozen water and its dependence on temperature, grain size and specific surface area has been well documented in previous studies (Anderson and Morgenstern, 1973).

Measurement of acoustic wave velocities in frozen soils may provide a key to assessing the amount of water that remains unfrozen (Nakano et al., 1972) and the change in mechanical behavior at low temperatures (Wang et al., 2006). The acoustic properties of different soils have been investigated by various researchers (Kurfurst, 1976; Nakano et al., 1972; Nakano and Arnold, 1973; Thimus et al., 1991; Wang et al., 2006). Nakano et al. (1972) have analyzed ultrasonic velocities of frozen soils in great detail. They measured compressional and shear waves in water saturated frozen soils and suggested that the decrease in compressional wave velocities was the direct consequence of the phase change from water to ice. Nakano and Arnold (1973) investigated the effect of ice saturation in frozen sand on the acoustic wave velocities. They found that the velocities of compressional and shear waves increased with ice saturation. Wang et al. (2006) measured acoustic wave velocities in three soil types; sand, loess, and clay and calculated the dynamic elastic constants. Their results indicate that the acoustic wave velocities and dynamic elastic constants of frozen soils are depended on freezing temperature and soil type.

The intend of this paper, is (a) to examine the acoustic properties of three soils at subfreezing temperature, (b) to estimate the unfrozen water content from measured ultrasonic wave velocities and compare the predicted and measured values, and (c) to estimate the dynamic strength properties.

2. Experimental methods

2.1. Principle of ultrasonic technique

A standard method for determining the ultrasonic velocities of materials is the immersion ultrasonic sing-around method. The ultrasonic sing-around method is based on the refraction of waves induced in a material (Nakano and Arnold, 1973) and allows for measurement of compressional and shear wave velocities using the same one system. The measurement principle of this method is illustrated in Fig. 1. An ultrasonic wave is emitted to a liquid by a transmitter and refracted at the liquid-frozen soil interface. In this

---

* Corresponding author. Tel.: +82 2 880 9310.
E-mail address: mchr023@snu.ac.kr (M. Christ).

0165-232X/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.coldregions.2009.05.008

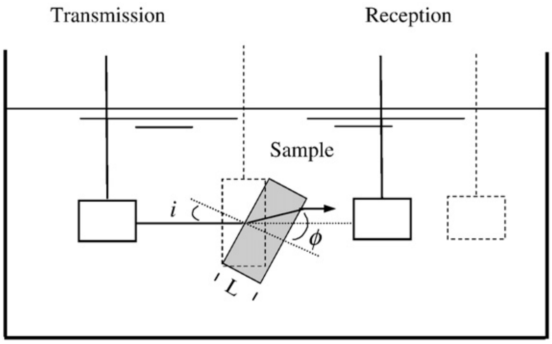

Fig. 1. Measurement principle of the immersion sing-around method.

study, kerosene was used as liquid for transmitting the sound wave. When the incident angle (i) is smaller than the critical angle for the compressional wave in the frozen soil, both compressional and shear wave propagate in it. Here, the critical angle refers to the angle by which the frozen soil is rotated for compressional and/or shear waves to propagate in the frozen soil. The induced waves propagate based on the theory of Snell's refraction given by:

$$\frac{\sin i}{\sin \phi} = \frac{V_0}{V} \tag{1}$$

where i is the incident angle, ϕ is the rotation angle, V_0 is the sound velocity of the liquid and V is the velocity of the frozen soil. When the incidence angle is $i=0°$, only the compressional wave propagates in the soil. The compressional wave velocity (V_c) is expressed as:

$$V_c = \frac{1}{\frac{1}{V_0} - \frac{T_1 - T_2}{L}} = \frac{L}{\frac{L}{V_0} - (T_1 - T_2)} \tag{2}$$

where V_c is the compressional wave velocity, L is the sample thickness, T_1 the travel time of the wave in the liquid and T_2 the travel time of the wave with the frozen soil immersed. If the incidence angle exceeds the critical angle for the compressional wave, only the shear wave propagates in it. The shear wave velocity (V_s) can be computed by:

$$V_s = \frac{1}{\frac{(T_1 - T_2)\cos(\phi)}{L} + \frac{\cos(\phi - i)}{V_0}} \tag{3}$$

where V_s is the shear wave velocity. At the frozen soil-liquid interface the wave is refracted again to the initial incident angle (i) and travels to the receiver. The ultrasonic equipment used consisted of an AC-M2 transmission/reception unit and UVM-2 Sing-around meter manufactured by Ultrasonic Engineering Co., Ltd., Tokyo, Japan. The received waveform was observed with an oscilloscope. The usable temperature of this equipment ranges from −50 °C to +80 °C with an average frequency of 2 MHz. The sample holder of the AC-M2 unit can be rotated ±60° with an accuracy of 1/10°.

Table 1
Soil properties.

Properties	Soil type		
	Sand	Silty-sand	Silt
G_s	2.70	2.65	2.50
γ_d (kN/m^3)	19.0	18.2	15.3
ω_{opt} (%)	11.9	11.7	19.8
Liquid limit (%)	27.5	35.2	39.5
Plastic limit (%)	19.3	22.8	31.1
USCS	SW	SM	ML

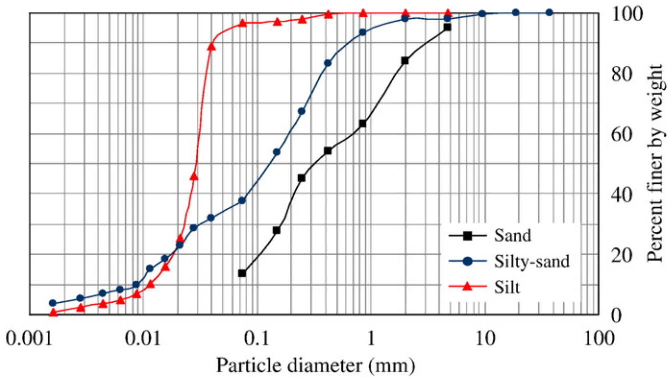

Fig. 2. Grain size distribution of tested soils.

2.2. Characteristics of materials investigated

Three types of soil: sand, silty-sand, and silt were chosen as fundamental soils. The sand represents a typical subgrade soil found beneath roads, while the silty-sand and silt are representative soil types of southern Far Eastern Siberia (Russia) sampled in the Khabarovsk region. The main physical characteristics of the soils are summarized in Table 1. The specific gravity and unit weight were measured according to ASTM D5550 and ASTM D698, respectively. Atterberg limits were performed following ASTM D4318. The grain size distributions were obtained based on ASTM D422 and can be seen in Fig. 2.

2.3. Frozen sample preparation for ultrasonic testing

To prepare test samples, oven dried soils were first mixed thoroughly with the appropriate amount of deaired water to achieve the optimum water content after which the materials were stored in sealed plastic bags for twenty four hours to insure uniform moisture distribution. For ultrasonic measurements the moistened soil was compacted into a mold, to form a disk sample with a diameter of 35 mm and a thickness of 6 mm. The sample was saturated by permeating water from the bottom of the mold. Then, the mold was closed at the top and bottom, which confined the sample to keep the variation of diameter and thickness constant. The sample was placed in a cold room and quickly frozen. Before testing the frozen specimens were carefully taken out from the molds and temperated at −20 °C for 24 h. The test sample conditions are given in Table 2.

2.4. Measuring ultrasonic velocities of frozen samples

The ultrasonic sing-around equipment was set-up in a cold room, were the room temperature could be controlled precisely (±0.2 °C). Then the frozen sample was carefully placed into the sample holder. Kerosene was used as cooling medium and as medium for transmitting the ultrasonic wave. The kerosene temperature in the tank was monitored by a thermocouple. The temperature of the frozen test

Table 2
Test conditions for ultrasonic measurements.

Properties	Soil specimen		
	Sand	Silty-sand	Silt
γ_d^a (kN/m^3)	19.0	18.2	15.3
γ_t (kN/m^3)	22.2	21.3	19.2
ω (%)	15.2	17.1	25.3
Void ratio	0.40	0.46	0.64
Porosity (%)	17.4	19.6	27.7
Saturation (%)	99.5	99.4	99.6

^{a}Maximum dry unit weight.

Download English Version:

https://daneshyari.com/en/article/4676453

Download Persian Version:

https://daneshyari.com/article/4676453

Daneshyari.com