



Dynamic behavior of fiber-reinforced soil under freeze-thaw cycles

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ABSTRACT

This research presents the dynamic behavior of fiber-reinforced soil exposed to freeze-thaw cycles. The series of dynamic triaxial tests were conducted on fine-grained soil mixed with different percentages of basalt and glass fibers subjected to freeze-thaw cycles. The results showed that after freeze-thaw cycles, with the addition of basalt and glass fibers, the damping ratio and the shear modulus increased at a constant confining pressure because of the increase of stiffness, but the shear modulus decreased with increasing shear strain. Moreover, the theoretical analytical formulations were developed to define for dynamic shear stress and dynamic shear modulus. The parameters were predicted by Hardin-Drnevich model and Kondner-Zelasko model. The shear modulus was expressed as a function of freeze-thaw cycles, fiber contents, confining pressure and initial water content. Finally, ten coefficients were calibrated by analyzing the experimental results and then employed to describe dynamic shear modulus of the fiber-reinforced soil.

1. Introduction

The dynamic properties of material used in geotechnical engineering were greatly influenced by dynamic shear modulus and damping ratio. In soil dynamic problems, stress-strain behavior of soil is always expressed by Hysteresis loops where the shear resistance and damping ratio is defined as the slope of lines related to top point of loops and the areas enveloped by loops, respectively. Many dynamic problems including earthquake incidence, machine vibrations, and ocean waves can be solved by the determination of energy absorption and stiffness of soil-structure interaction. Moreover, recent researches on geotechnical engineering technology indicated that soil reinforcement improves the resistance of soil against compression and tension. In terms of the wide use of soil reinforcement in geotechnical engineering, the potential benefit of soil reinforcement under dynamic loading should be investigated. In the literature, many experimental and numerical researches have been focused on the reinforced soil with different types of fiber. These results showed that the tensile strength of soil can be improved obviously with the fibers [1–7]. On the other hand, recent studies on liquefaction potential of fiber-reinforced soil have shown that the liquefaction of retaining structures, embankments and subgrade soil was influenced by fiber content, fiber length and number of loading cycles [8–14].

Dynamic characteristics of reinforced soils are greatly influenced by

many parameters such as fiber content, fiber length, freeze-thaw cycles, loading repetition, confining pressure, frequency and shear strain amplitude. Shahnazari et al. [15] investigated the dynamic effects of reinforced sand with carpet and geotextile strips by conducting large and small scale of cyclic triaxial tests. The results showed that the shear modulus of reinforced soils decreased in the low confining pressures (less than 100 kPa) and increased in the high confining pressures [15]. Naeini and Gholampoor (2014) carried out a number of cyclic triaxial tests on reinforced silty sand with geotextile. Their results showed that the dynamic axial modulus increased and the cyclic ductility of silty sand for all silt contents decreased with the increments of number of geotextile layers and confining pressure. Moreover, with the addition of silt up to about 35%, dynamic axial modulus reduced and cyclic ductility increased [16]. Also, Sadeghi and Beigi (2014) conducted a number of triaxial tests to examine the effect of fiber content, deviator stress ratio, confining pressure, and number of loading cycles on secant dynamic shear modulus of fiber-reinforced soil. The results indicated that an increment of deviator stress ratio caused a decrease on the dynamic shear modulus at a high confining pressures. Also, the increment of dynamic shear modulus with loading repetition was expressed at a large deviator stress ratio [17]. Kirar et al. [18] conducted a large number of undrained cyclic triaxial tests on the cylindrical unreinforced and reinforced sand specimens with different percentages of coir fiber. The authors concluded that the effects of fiber content were expressed

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Table 1
The particle size distribution and the engineering properties of clay soil.

Grain composition* (%)				Dry density gr/cm ³	Optimum water content (%)	Plasticity index
d > 0.01	0.01 ≥ d	0.005 ≥ d > 0.005	d ≤ 0.001	1.80	18.03	8.05
67.29	11.16	15.95	5.59			

* Determined by a laser particle size analyzer Mastersize 2000.

*Classified as CL according to the Unified Soil Classification System.

as a function of stress–strain amplitude and confining stress. It was found that effect of fiber content was significant on both dynamic shear modulus and damping ratio especially at higher shear strain amplitude [18]. Nakhaei et al. [19] carried out large-scale consolidated-undrained cyclic triaxial tests on reinforced soil with granulated rubber and specific granular soil to investigate the effects of reinforcement materials on dynamic shear modulus and damping ratio. Their results showed that the dynamic shear modulus increased with increase of confining pressure and decreased with the increase of the rubber content. Furthermore, the damping ratio decreased with the addition of rubber under low confining pressure ($\sigma_c = 50$ kPa and 100 kPa) and increased with increase of rubber content under high confining pressure [19].

Moreover, various models and methods related to failure criteria, plastic theory and limit analysis under dynamic loading were developed by many researchers to investigate the dynamic behavior of reinforced soil [3,20–28]. On the other hand, soil reinforcement with different types of fiber plays a significant role in mechanical and thermal properties of soil. In this study, two different types of fiber including glass fiber and basalt fiber were used to investigate their effects on the dynamic and physical properties. The glass fiber with different blended ratios was often used to investigate the engineering properties of soil. However, this fiber was not studied enough under freeze-thaw cycles in the literature. Further, the glass fiber has the wide use in civil and highway engineering. In this application, the glass fiber presents effective bulk density, hardness, stability, flexibility and stiffness. Besides, the basalt fiber was not studied enough in reinforced soil to improve engineering properties although these fibers are generally used as an alternative to metal reinforcements in building materials, such as steel and aluminum. Moreover, the basalt is used in reinforcement

technology to stabilize the pavement by decreasing effects of cracks caused by excessive traffic loading, age hardening and temperature variations. In view of these useful and advantageous properties of basalt and glass fibers, physical properties and dynamic behavior of reinforced soil by all these fibers subjected to freeze-thaw cycles were studied.

The aim of this research was to elucidate the effects of freeze-thaw cycles on physical properties and dynamic behavior of reinforced clayey soils with randomly distributed glass and basalt fibers. For this purpose, dynamic triaxial tests were conducted under different number of freeze-thaw cycles, fiber contents, and confining pressures. The theoretical analytical formulations proposed by Hardin-Drnevich model and Kondner-Zelasko model were used to determine dynamic shear stress and dynamic shear modulus. The dynamic shear modulus, G_d , was expressed as a function of fiber content (χ), confining pressure (σ_c), water content (w) and freeze-thaw cycle (N). Finally, ten constitutive coefficients of the theoretical analytical formulations were calibrated by analyzing the experimental results, which were then employed to define the G_d of the fiber-reinforced soil.

2. Laboratory experiments

2.1. Tested material

In this paper, clay soil from the Qinghai-Tibet Plateau in China was used to study the dynamic behavior. The particle size distribution and engineering properties of the clayey soil are shown in Table 1.

The specimens were reinforced by basalt and glass fibers with the same length and diameter. Further, the specimens were blended with 0%, 0.5% and 1% ratios of fibers. The basalt and glass fibers were derived from Hebei province in China and relevant engineering properties are presented in Table 2.

2.2. Specimen preparation

The size of the columns specimens were 125 mm in height with a diameter 61.8 mm. For every mixture, the exact weight of each additive material was defined based on optimum moisture content and maximum dry density obtained from the standard Proctor test. Dry soil was mixed with water before the fibers were incorporated uniformly and all soil specimens were compacted by three layers.

2.3. Freeze-thaw performance

The freeze-thaw tests were carried out on the two different parts.

Table 2
Mechanical and physical properties of the studied basalt and glass fibers [29].

	Basalt Fiber	Glass Fiber
		
Breaking strength	3900 MPa	3450 MPa
Modulus of elasticity	86.2 GPa	74 GPa
Breaking extension	3.1%	4.7%
Fiber diameter	10 μ m	10 μ m
Linear density	60–4200 tex	40–4200 tex
Length	15 mm	15 mm

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