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Small-strain shear modulus of volcanic granular soil: An experimental investigation

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ABSTRACT

While volcanic soils exist in many places around the world, their mechanical behavior is however less extensively studied as compared to the conventional soil type such as quartz sand and clay. This paper presents an experimental study investigating the small-strain shear modulus (G_0) and associated shear wave velocity (V_s) of a volcanic granular soil collected from the northeast of Japan that was affected by the devastating 2011 Tohoku earthquake. Reconstituted soil specimens were tested at different packing densities and confining stress levels by using the resonant column technique, and the pressure and density dependence of shear modulus was established for the soil. The study showed that under otherwise similar conditions, the G_0 value of the volcanic soil was markedly lower than that of clean quartz sands, but it tended to increase significantly when the fine particles in the soil were removed. This finding suggests that the presence of fines plays an important role in the mechanical behavior of volcanic soils. A practical model accounting for the influence of fines and the pressure and density dependence is proposed and it is shown to provide reasonable estimates of G_0 for both volcanic soils and clean quartz sands studied.

1. Introduction

The shear wave velocity (V_s) or associated small-strain shear modulus ($G_0=\rho V_s^2$) is an important soil property needed in almost all earthquake geotechnical engineering problems, particularly in earthquake ground response analysis and liquefaction evaluation [1–3]. In the last few decades, a great number of laboratory studies have been conducted to determine G_0 and V_s values for quartz sands and clays by using the resonant column or bender element tests [1,4–15]. These studies have produced valuable data showing that the small-strain shear modulus is affected by various factors and among them the effective confining stress and void ratio are two most important ones. Compared with quartz sands and clays, volcanic soils can be regarded as a non-textbook type of soil. Available studies on their mechanical behavior are rather limited although they are found in many places around the world, particularly in the Pacific Rim region [16–18]. It has been frequently observed in recent years that natural deposits and earth structures composed of volcanic soils are susceptible to geohazards such as earthquakes and landslides [17,19], raising a pressing need for more comprehensive studies of the mechanical properties of this type of soils.

This paper presents an experimental study investigating the small-strain shear modulus of a volcanic granular soil collected from a site in the northeast of Japan, which suffered severe ground failures during the 2011 Tohoku earthquake (Fig. 1). A series of resonant column tests was performed on specimens of the soil at various packing densities and effective confining stress levels. Both the original volcanic soil samples and the sieved soil samples where fine particles (diameter <63 μm) in the original soil were removed were studied, with the purpose of examining the influence of the fines on the small-strain property. In addition, the G_0 values of two clean, uniform quartz sands were also measured using the same method, and were compared with those of the original and sieved volcanic soil samples. Based on these comparisons, a predictive model is proposed that may be used as a first approximation to estimate G_0 values for both volcanic soils and quartz sands under a range of confining stresses and void ratios.

2. Experimental program

2.1. Material

The volcanic soil was collected from a site located in the County of Naganuma, Japan. The particle size distribution curve

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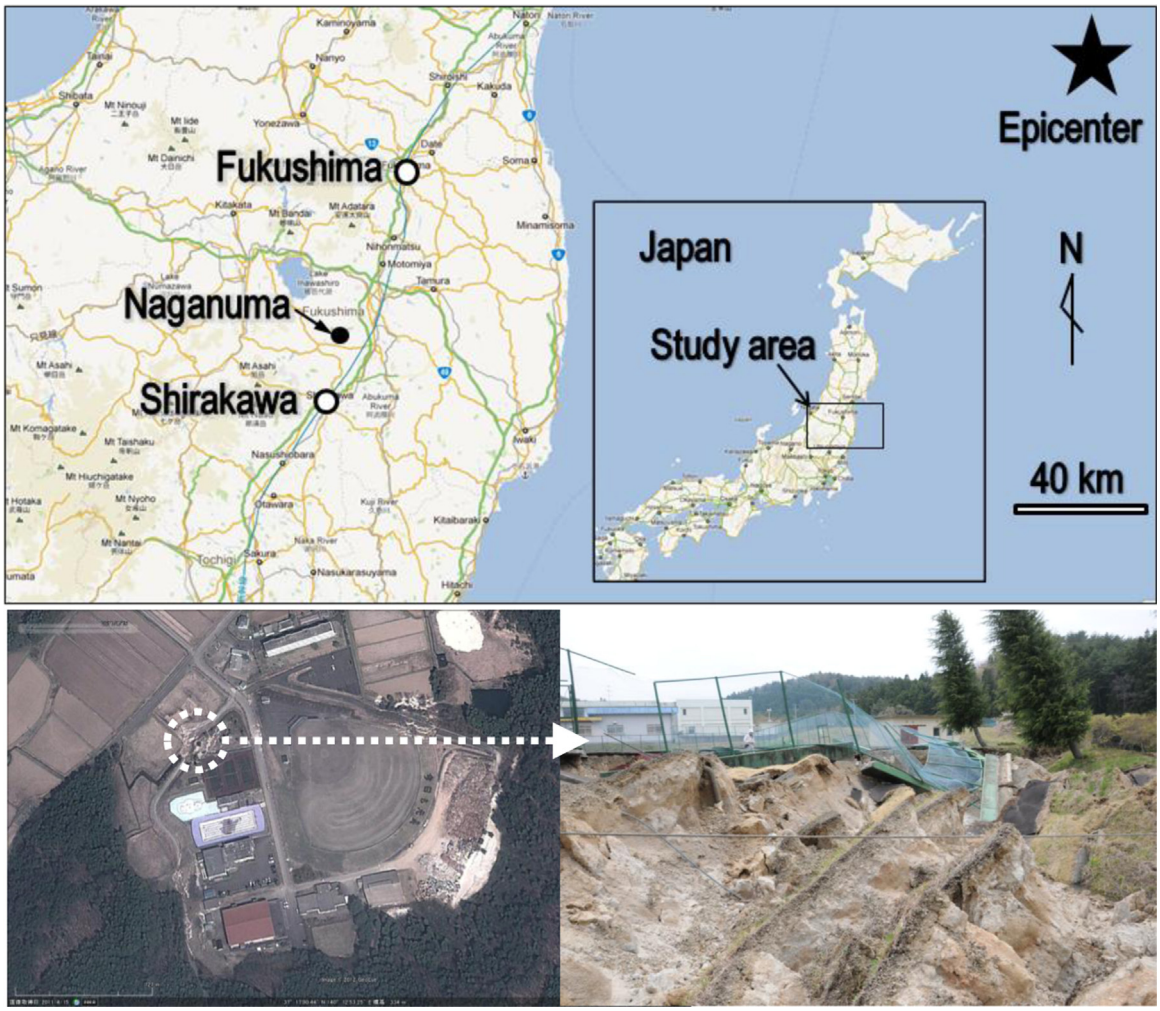

Fig. 1. Location of volcanic soil samples.

of the soil was determined by dry sieving and sedimentation tests, as shown in Fig. 2. For the purpose of comparison, the grading curve of Toyoura sand, a clean quartz sand that has been widely used in geotechnical engineering research [11,20], is also included in the plot. Apparently, the volcanic soil has a wider range of grain size, with a mean size of 982 μm and the coefficient of uniformity of 4.39. The percentage of fine particles (<63 μm) in the soil was measured to be 5–7% by weight, which is significantly less than that (23%) of the volcanic soil at the Aratozawa landslide site in the prefecture of Miyagi, Japan [19], but is greater than the fines content (0.3%) of the volcanic soil in Mori prefecture of Japan [17]. The plasticity index of the fines was determined to be 26.2. The specific gravity of the volcanic soil was measured to be 2.56, which is slightly lower than that of Toyoura sand (2.65), but slightly larger than that of the volcanic soil at the Aratozawa landslides site (2.47). Compared to the volcanic soil in Mori ($G_s=2.82$), its specific gravity is markedly smaller. More detailed information about index properties of the volcanic soil is summarized in Table 1.

Images were taken for soil grains sorted by size using a light microscope, as shown in Fig. 3. Generally, these grains are more angular and irregular than Toyoura sand grains. A careful examination of the images indicates that there are four major types of minerals in the volcanic soil, as shown in Fig. 4; they are amphibole (black and elongate), plagioclase (gray and blocky), quartz (colorless and translucent) and pumice (brown with rough surface). Among these minerals, pumice has been found in many volcanic soils; it is a lightweight porous material typically formed during explosive volcanic eruptions. Because of the existence of the intra-particle voids, pumice is prone to crushing when subjected to loading. In recent years pumice has been used as a construction material for producing lightweight concrete and subgrades of pavements [21].

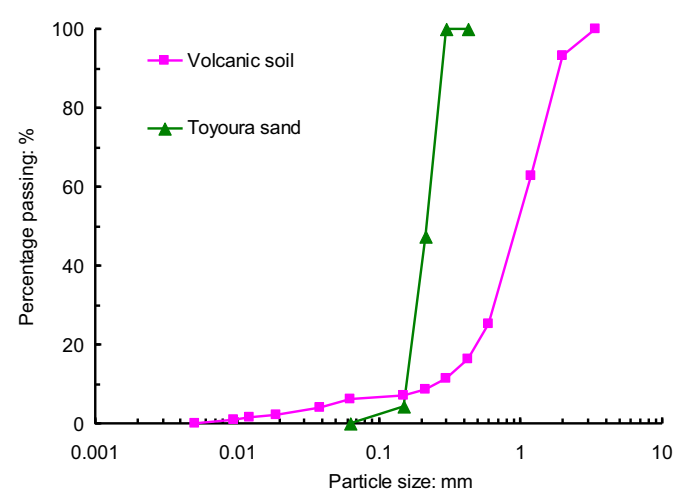

Fig. 2. Particle size distribution curves of volcanic soil and Toyoura sand.