

FURTHER INSIGHTS INTO THE PROPERTIES, MICROSTRUCTURE AND SMALL STRAIN SHEAR MODULUS OF ALLOPHANIC VOLCANIC ASHES

ゴビン, ムクテシェワー

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氏 名 : MUKTESHWAR GOBIN (ムクテシェワー ゴビン)

論 文 名 : FURTHER INSIGHTS INTO THE PROPERTIES, MICROSTRUCTURE AND SMALL STRAIN SHEAR MODULUS OF ALLOPHANIC VOLCANIC ASHES

(アロフェン質火山灰土の微細構造と微小ひずみレベルにおける変形特性に関する研究)

区 分 : 甲

論 文 内 容 の 要 旨

The small strain shear modulus, $G_{\max}$ is an important parameter in soil dynamics problems. $G_{\max}$ has been routinely estimated by seismic tests (like cross-hole tests) in the field or by resonant columns and triaxial cyclic tests in laboratory. The bender element (BE), which can be incorporated in several equipment, provides a simpler method for estimating the shear wave velocity, V_s from which $G_{\max}$ can then be evaluated. $G_{\max}$ is influenced by factors like void ratio, effective confining stress, time or aging (beginning with the consolidation stage) and in the case of BE by input wave frequency as well. However, technical standards for BE, pretty much leaves it to the judgement of users for selecting the input wave frequency, which affects the accuracy of the results. The effect of time on $G_{\max}$, has also been mostly neglected.

It has been highlighted that the small strain mechanical behaviour of volcanic soils is less extensively studied compared to conventional sandy and clayey soils. Large areas of the Kyushu Island in the south of Japan are covered with black allophanic volcanic ashes (locally known as kuroboku), which are used as geomaterials. Natural deposits and earth structures suffered considerable damages during recent earthquakes and landslides events. It was also reported that $G_{\max}$ data for the kuroboku soils was not readily available for modelling geo-disasters during the 2016 Kumamoto Earthquake. Researchers, hence, resorted to using $G_{\max}$ data for volcanic ashes from other countries. Moreover, some volcanic soils consist of clay minerals like allophane and imogolite, the influence of which also does not seem well appreciated. Indeed, Geotechnical Engineering publications related to the 2016 Kumamoto Earthquake mentioning these two clay minerals were almost inexistent. From the foregoing, using allophanic kuroboku soils, sampled from two sites in Kyushu Island, we aimed at shedding more light on the characteristics and microstructure of this material. The effect of the input frequency on shear waves was also studied to provide an objective criterion for its selection. In addition, the influence of the effective confining stress, void ratio, gradation (through the coefficient of uniformity) and time on the small strain properties of this type of soil was investigated, in order to propose empirical equations for estimating the small strain modulus of the allophanic kuroboku soils.

The dissertation has been arranged according to the following chapters, herein described in brief:

Chapter 1 began with the background information related to the small strain shear modulus. Methods for measuring this parameter were introduced and how the BE became a popular alternative to other laboratory methods. The main influencing factors on the determination of $G_{\max}$ were briefly described. Details were also given about how studies on volcanic soils is limited compared to conventional geomaterials, how the characteristics and influence of allophane and imogolite minerals are not so well appreciated and how existing relationships on conventional geomaterials may not be applicable to volcanic soils. The objectives, original contributions and research flow of this study were also presented in this chapter.

Chapter 2 was concerned with the review of literature. Additional information about volcanic soils and

geo-disasters like the 2016 Kumamoto Earthquake were at first given. An overview of the clay minerals allophane and imogolite was provided. Details about field and laboratory methods for estimating the $G_{\max}$ were laid out. Some case studies demonstrating the usefulness of the small strain shear modulus were presented. The characteristics, advantages and reliability of BE were discussed. Further information about the main influencing factors of $G_{\max}$ such as void ratio, effective confining stress and time as well as secondary factors like fines content, soil disturbance and particle shape were provided.

Chapter 3 elaborated on the geology of the sampling sites and properties of the allophanic volcanic ashes used in this research. These included the specific gravity, the grain size distribution, liquid and plastic limits. Details were given about some non-textbook characteristics of these types of soil and how a different approach was used to estimate the moisture content. Using the plasticity chart, the allophanic volcanic ash, kuroboku was classified in comparison with similar volcanic ashes found in other parts of the world.

Chapter 4 described the laboratory testing equipment and methodology. The procedures adopted to sieve and store the soil samples were provided. Details for carrying out triaxial tests were given, especially sample preparation and saturation methods. The methodology used to perform BE tests was elaborated. Methods for interpreting the waveforms and the equations for estimating the shear wave velocity and $G_{\max}$ were introduced. Furthermore, the procedures followed to carry out the micrographic analysis using Scanning Electron Microscope (SEM) and Field Emission Scanning Electron Microscope (FE-SEM) were also discussed.

Chapter 5 described the microstructure of the soil according to the soil components, particle interaction and pore space. The allophanic volcanic ashes consist of different types of porous particles in different configuration and at different internal spatial scales. Both SEM and FE-SEM images were used to observe the microstructure of the kuroboku soils at the assemblage and elemental levels. The micrographs showed that allophane, imogolite and volcanic glass were the dominating soil constituents. Particles would interact mostly through face to face contact and the pore space was composed of macropores, mesopores as well as micropores.

Chapter 6 presented the effects of different factors on the $G_{\max}$. Firstly, the influence of input wave frequency and near field effects was shown. Methods to estimate the input wave frequency were also proposed, which included modal analysis. Results for the influence of void ratio, effective confining stress, gradation and time were presented. Observations and inference made from micrographs (Chapter 5) were key to explain the slight differences in $G_{\max}$ noted among the allophanic volcanic ashes. For instance, presence of diatoms contributed to an additional shear stiffness to Soil 1 and its sieved components at low effective confining stress. Due to the strong electrostatic bonding, the allophanic kuroboku soil behaved like a pseudo-granular material, with the primary consolidation stage completed within a few minutes. The long term growth in $G_{\max}$ was not strictly linear but rather increased almost in phase with the three creep stages.

Chapter 7 started with first further details about existing empirical equations for estimating $G_{\max}$. Using data from Chapter 6, empirical equations with void ratio and effective confining stress as the only independent variable were proposed. The results were presented together with other materials not limited to volcanic soils. It was found that the kuroboku soils had similar $G_{\max}$ as normally consolidated clays. An equation that could be used to estimate the $G_{\max}$ of volcanic soils in general was also proposed. By introducing a time factor in the empirical equations, a more reasonable prediction of the long term $G_{\max}$ could be made.

Chapter 8 concluded with the achievements and the discussion for the whole dissertation. Some recommendations for further works were also suggested.