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Analytical investigation of disturbance of seabed-sampled soil specimens and its influence on unconfined strength

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Abstract

In view of the need to utilize ocean space and to develop seabed resources, the assessment of the stability of deep seabed soil has emerged as an important challenge in the field of geomechanics. To study seabed stability, the strength and stiffness of the natural ground must be ascertained. Accordingly, it is necessary either to conduct laboratory testing on soil specimens sampled from the seabed or to estimate the strength and stiffness by in-situ tests. While in the future it may be reasonable to conduct in-situ tests to estimate the stiffness and strength of seabed soil, it will still be necessary to compare the physical properties measured by in-situ testing with those measured by laboratory testing in advance of these determinations. In short, soil specimens must be sampled from the actual deep seabed, and laboratory mechanical tests must be conducted on the sampled soil specimens. However, soil sampled from the ocean bottom is subject to effects that differ from those exerted on soil sampled from the earth. More specifically, the non-negligible effects of disturbance are expected with soil sampled from the ocean bottom. The effects of disturbance occur during the sampling process due to the vaporization of dissolved gases, as these soil specimens are under relatively higher pressure and contain pore water with a high amount of dissolved gases. Therefore, numerical simulations were conducted in the present study to investigate the effects of vaporized dissolved gases on the mechanical behavior of soil specimens during sampling and on the undrained shear strength as determined by laboratory tests. The analyses revealed that the combination of the decreasing effective stress caused by the sampling and factors such as overconsolidation and unsaturation is attributable to the difference between the soil strength ascertained by laboratory testing and the in-situ soil strength.

Keywords: Disturbance; Marine clay; Unsaturated soil; Numerical simulation; Henry’s law; Unconfined undrained test

1. Introduction

Since the discovery of methane hydrates (1930), cross-disciplinary scientific efforts have been directed towards clarifying the properties of deep seabed soil for the purpose of developing ocean seabed resources. Such efforts include Project Mohole (1961), the Deep Sea Drilling Project (DSDP, 1968), the International Phase of Ocean Drilling (IPOD, 1975), the Ocean Drilling Program (ODP, 1985), and the Integrated Ocean Drilling Program (IODP, 2003). However, in identifying the mechanical properties of deep seabed soil, it is difficult to ascertain the effects of the disturbance arising from the release of stress that specimens undergo during sampling. In this regard, pressure core sampling (Kubo et al., 2014) has been explored. However, this method lacks the theoretical basis to quantify the effects of the disturbance on specimens and remains at an undeveloped stage of understanding to interpret the test results. It has been pointed out that changes in the mechanical properties of sampled soil specimens are caused by the

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effects of the mechanical disturbance occurring during sampling or testing and of the disturbance arising from the release of stress. In these respects, the mechanical disturbance has been studied by Ladd and Lamb (1963) and Okumura (1969), followed by Tsuchida et al. (1988) and others (Mitachi et al., 2001; Tanaka and Tanaka, 1995). Similarly, Skempton and Sowa (1963) and Noorany and Seed (1965) were forerunners in terms of studies on the disturbance arising from the release of stress. Since then, researchers have worked to study the effect of changes in the effective stress of specimens resulting from the release of the confining pressure exerted on the undrained shear strength of specimens. This is a classic topic in geomechanics. Soil sampled from the deep seabed is unavoidably subject to the effects of mechanical disturbance, which remains to be reduced by developments in sampling technology. Even so, it is highly likely that the effects of the stress release after the removal of the high confinement pressure will continue to be a serious problem. Reported experiments have revealed the substantial effects of gases on the variation in momentary pressure in ordinary ground sediments (Tsui and Helfrich, 1983). Additionally, marine clay soil specimens sampled close to waterfront locations have exhibited residual effective stress measurements far smaller than those forecasted (Matsumoto et al., 1969) as well as measured degrees of saturation that decreased with depth (Fujishita, 1965). On the other hand, despite the fact that a residual effective stress larger than 98.1 kPa is apparently impossible in fully saturated soil, effective stress larger than 98.1 kPa has been measured in undisturbed samples collected from large depths (Watabe and Tsuchida, 2001). These findings have led to one of the most important problems in today's seabed soil surveys: the vaporization of dissolved gases that degrade the quality of the sampled specimens needed to ascertain the mechanical properties (Okusa, 1984). Recently, microscopic images of sampled specimens have illustrated that the gases were contained within the soil voids as small bubbles (Amaratunga and Grozic, 2009). This becomes a more serious problem with deep seabed soil. It is quite probable that soil from the deeper seafloor contains a larger amount of dissolved gases (Grozic et al., 2000; Kortekaas and Peuchen, 2008). In addition, sampling from such a deep ground involves substantial changes in pressure. Consequently, dissolved gases that vaporize due to these changes in pressure, which have not been accounted for at different water and seabed depths (i.e., depth below the seabed floor) in existing studies, are likely to exert an apparent effect.

The effects of the vaporization of dissolved gases can be explained by taking diver's disease as an example. Diver's disease, also known as "decompression sickness", or DCS, can be experienced by a diver after scuba diving. Nitrogen gas accounts for approximately 78% of air. Accordingly, when a diver uses an air cylinder, nitrogen gas dissolves into the diver's body. Larger amounts of nitrogen gas dissolve with increasing depths and increasing diving time. When a diver rises rapidly towards the sea surface at the end of the dive and the water pressure decreases, the dissolved nitrogen forms bubbles in the diver's body. The bubbles apply pressure on the nerves and joints of the diver, causing pain and abnormal sensations. This is the cause of diver's disease (Fig. 1). In the case of sampling specimens from the seabed, it is highly likely that phenomena similar to diver's disease will occur. During the process of sampling specimens from the seabed, large amounts of gases dissolved in the pore water of the saturated soil vaporize owing to the decreasing water pressure. Consequently, the soil becomes unsaturated (Fig. 2). This unsaturation process is thought to be one of the causes of the disturbance of sampled specimens, affecting changes in the effective stress. In recent years, the use of a pressure-conserving corer to maintain the in-situ water pressure during sampling has become possible. This method appears to be effective for preventing the vaporization of dissolved gases otherwise resulting from changes in pressure during sampling. However, this sampling method is immensely laborious and costly, making it difficult to sample many specimens. Therefore, it is necessary to propose an optimal test method for estimating the in-situ strength from sampled specimens by evaluating the disturbances in the specimens sampled by the conventional sampling technique. Okumura (1969a) used Boyle's law and Henry's law to theoretically calculate the effects exerted by gases contained in pore water on the residual effective stress of specimens. For this theoretical reasoning, Okumura used a total stress analysis to solve problems as well as coefficient B proposed by Skempton (1954) to estimate the residual effective stress. At the time of the study, many key ideas, such as the mechanics of unsaturated soil, were yet to be proposed. To ensure equilibrium, the total stress acting on a specimen was believed to equal the atmospheric pressure. However, the gas pressure produced by dissolved gases is not negligible; and therefore, researchers began to believe that the effective stress formula for saturated soil is incapable of predicting changes in effective stress in seabed soil (Esrig et al., 1977). It has become possible recently to explore the mechanical behavior of unsaturated soil due to a successful systemic arrangement of the mechanics of unsaturated soil and a soil/water/gas coupled analysis. On the basis of contemporary mechanics, it is not necessarily true that the pore gas pressure in a specimen is in equilibrium with the atmospheric pressure because, in actuality, suction occurs within the specimen. Thus, to examine the effects of dissolved gases on the quality degradation of sampled specimens, it is necessary to use the soil/water/gas coupled analysis. In this study, the pore gas pressure is expressed by the gauge pressure.

Given this situation, the purpose of the present study is to examine the effects of changes in the state of dissolved gases on the mechanical behavior of sampled specimens and on the undrained strength determined through laboratory testing. For this purpose, the study uses a mathematical model capable of representing changes in the state of dissolved gases and simulating sampling processes with