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Comparing the quality of samples obtained by three types of fixed-piston samplers for soft sensitive clay

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ABSTRACT

Three types of fixed-piston samplers were employed at Nakdong River Delta. The retrieved samples were equally divided into 100 mm long pieces. Quality was evaluated using suction, shear wave velocity, and consolidation tests. The constant rate of strain consolidation test, rather than the incremental loading test, produces a better correlation with the nondestructive test results. The sample quality progressively degrades from the near-center to both ends of each sampling tube. The sample quality measured using the three methods on samples at the near-center of the sampling tubes consistently varies with the in-situ void ratio in the upper clay; however, such a trend is not observed in the lower clay. This may be attributed to the effect of total stress relief on the clay. The sample quality evaluated deteriorates in the following order: oil-operated type, mechanical type, and hydraulic type. The results suggest that the difference in sample quality is principally caused by the mechanical disturbance attributed to the different penetration mechanisms (methods) of the sampling tubes. The tip angle of sampling tubes significantly affects sample quality, whereas the length-to-diameter ratio has a relatively insignificant effect.

1. Introduction

Sample quality significantly affects the safety of, and costs involved in, construction projects, particularly those located in clay deposits. One or more sampler types are selected for geotechnical investigation depending on factors such as local standards, feasibility, applicability, economical efficiency, and the importance of the specific construction project. Large-diameter samplers, such as those produced by Sherbrooke (Lefebvre and Poulin, 1979) and Laval (La Rochelle et al., 1981), can obtain samples with excellent quality. However, these samplers are expensive and are limited to depths of 15 m to 25 m. The most extensively used samplers worldwide which do not have depth limitations are the mechanically (mechanical types) and hydraulically activated (hydraulic types) fixed-piston samplers. These samplers were originally developed by Hvorslev (1949) and Osterberg (1952) and have subsequently been improved or modified over the years. The mechanical sampler (Japanese Geotechnical Society, 1221–1995, 1998) is considered more advantageous and comes close to achieving the requirements of an all-purpose sampler. These requirements include a constant and continuous rate of penetration, the release of vacuum induced during sampling, and unlimited sampling depths (Clayton et al., 2002). The mechanical sampler has been proven to obtain good quality samples based on its use in various clays. However, the geometry and dimensions of the sampling tubes, rather than the samplers themselves, were generally considered as the main determinants of sample quality (Baligh et al., 1987; Clayton et al., 1998; Hight, 2001; Tan et al., 2002). Hydraulic samplers have long been extensively used in many countries, including Korea (KS F, 2317, 2006) and the US (ASTM D 6519-05, 2007). An interesting application of such samplers can be found in numerous geotechnical investigations in the reclamation area of the Nakdong River Delta over the last two decades. The clay deposits of this area vary from 20 m to 70 m in thickness and are classified as young and normally-consolidated clay. However, engineers have yet to evaluate the geotechnical properties of this clay successfully. One reason for this failure is the poor quality of samples. For example, the overconsolidation ratio (OCR) determined from oedometer tests has been less than 1.0 for most depth levels, and the value decreased with depth greater than approximately 15 m (Chung et al., 2002a,b). The aforementioned facts caused most researches (Tan et al., 2002; Tanaka and Tanaka, 2006; Landon et al., 2007; Takemura et al., 2007; Donohue and Long, 2010) to focus on the comparison of the quality of samples retrieved by various sampling

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types. The sample quality evaluation was conducted in the following order: larger diameter samplers, fixed-piston samplers, and pistonless Shelby tube sampler.

Improvements in the quality of samples obtained by the fixed-piston samplers were attempted by changing the geometry and dimensions of the sampling tube (Clayton et al., 1998; Hight, 2001), as well as the application of low water pressure during drilling or cleaning of the boreholes (Chung et al., 2004; Chung, 2005). It should be noted that samplers with different dimensions and geometry of their respective sampling tubes were used to prove the former fact (Tan et al., 2002; Tanaka and Tanaka, 2006). The advent of an oil-operated fixed-piston sampler resulted in the re-evaluation of the fixed-piston sampler types. The oil-operated sampler was developed to be comparable with the hydraulic sampler in terms of use (easy operation and cheap sampling) and with the mechanical type in terms of function (vacuum breaker and constant advancement) (Chung and Kweon, 2013). The application of the newly developed sampler produced a significantly better sample quality than the hydraulic sampler. Therefore, a comparison of sample quality between the three samplers is desirable. Additionally, the effect of the different sampling tubes used with a sampler requires investigation.

This study primarily evaluates the effects of fixed-piston samplers and the dimensions and geometry of the corresponding sampling tubes on sample quality. Three types of fixed-piston samplers, namely, the hydraulic, mechanical, and oil-operated, with the same diameter and tip edge of sampling tube but with varying lengths, were applied at a site of the Nakdong River Delta. Additionally, a larger diameter and a different tip edge of sampling tubes were applied to the oil-operated sampler. The recovery ratio of the samples and the condition of the sampling tubes were initially observed. The sample qualities were then assessed by comparing the mean effective stress and shear wave velocity of the samples in the laboratory with those in the field and by using the consolidation parameters obtained using two testing methods. Additional consolidation tests were conducted to evaluate the effects of consolidometers and testing methods on the sample disturbance, as well as of sample desaturation induced after sampling. Moreover, the correlations among the sample qualities obtained by the three samplers with different sampling tubes and the causes of the varying quality are discussed.

2. Three types of fixed-piston samplers

Fig. 1 shows the schematic diagrams of three types of fixed-piston samplers: mechanical (JGS 1221–1995), hydraulic (ASTM D 6519-05, 2007), and oil-operated (Chung and Kweon, 2013). These samplers are capable of advancing a sampling tube at a high and continuous speed after a borehole is created, as well as of releasing the vacuum that occurs between the fixed piston and soil during sampling. In the mechanical type, the lowering (or withdrawal) of the sampler is necessary to connect (or separate) both the drill and extension rods in the borehole. The sampling tube is advanced by keeping the extension rods fixed and then pushing the drill rods (or pipes) continuously downward using the drilling machine. The advanced length should be carefully controlled so as not to exceed the effective length, which is the distance from the top of the fixed piston to the top of the sampling tube. After the sample is taken, the sampler is withdrawn from the borehole to the ground surface by reversing the process. The suction between the piston and the tube is released prior to disassembly using a vacuum breaker (Figure 1a). Hence, the mechanical sampler is advantageous and comes close to achieving the requirements described above. The disadvantages of the mechanical samplers principally lie in their cost and their complexity of use (Clayton et al., 2002).

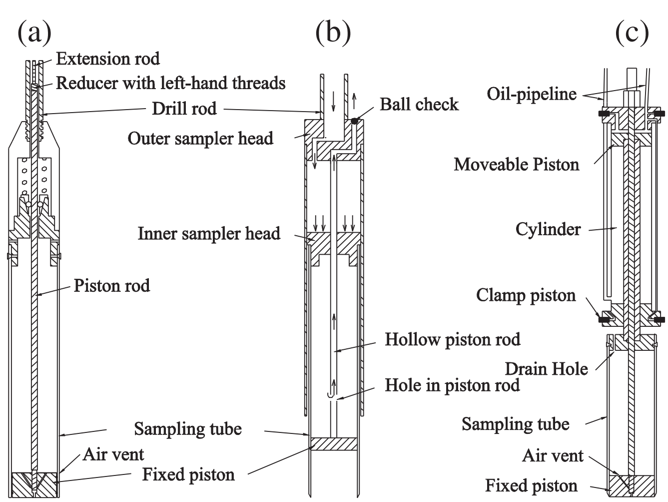

Fig. 1. Fixed-piston samplers.

A hydraulic fixed-piston sampler is lowered or withdrawn only by the connection of the drill rods to a desirable depth in the borehole. The sampling tube is advanced by means of fluctuating water pressure, which is supplied by one or two water pumps. Advancing of the sampling tube is automatically stopped when it reaches the effective length. At this point, the applied water is flushed out through the outlet hole (Figure 1b). Hence, hydraulic samplers are easy to assemble, operate, and disassemble. Their disadvantages include difficulty in continuous advancement because of the fluctuating water pressure, and the lack of a vacuum breaker (KS F 2317, 2006). The use of clear water is also recommended when advancing hydraulic-type samplers because the sand particles suspended in the drilling mud are abrasive and can damage the O-ring seals in the moving parts (US Army Corps of Engineers EM1110-1-1804, 2001).

An oil-operated sampler, with attached oil-supply hoses, is also lowered or withdrawn by connecting the drill rods in the borehole. The speed of the advancement of the sampling tube is controlled using a hydraulic valve system, which is connected to an oil pump on the drilling machine (Figure 1c). The advancement is automatically stopped when the sampling tube reaches the effective length. The vacuum between the sample and the top of the fixed piston is released prior to disassembly, as in the mechanical type. If a steel casing is used, the sampler is fixed by the advancement (i.e., expansion) of the clamp pistons in the center of borehole. Hence, the main advantages of this sampler lie in its simplicity and cost-effective use, similar to the hydraulic sampler. However, this oil-operated sampler has a better penetration mechanism than that of the mechanical type. The long length of this oil-operated sampler as well as its accompanying hoses may be cumbersome. Detailed descriptions of sampler's principle and its operation are given by Chung and Kweon (2013).

In summary, the oil-operated and the mechanical samplers can advance the sampling tube at a continuous and high speed, as well as equip a vacuum breaker. Meanwhile, the hydraulic sampler may advance the sampling tube discontinuously and may fail to equip the vacuum breaker. The oil-operated sampler can be fixed during advancement. Compared with the other two samplers, the mechanical type requires a longer time to lower (or withdraw) the sampler. Hence, this sampler is cost-ineffective.

3. Site description

The test site is located in the floodplain (i.e., marginal basin) of the Nakdong River Delta, Busan City, South Korea (Chung et al., 2012). The geotechnical properties of the site are shown in Fig. 2. The soil profile at the test site consisted of a silty sand layer that was 5 m thick, a soft-to-medium (with undrained shear strength of 12–40 kN/m^2) and sensitive (water content is larger than the liquid limit) layer of silty clay that was 20 m thick, and a sandy layer on top bedrock. The deposit was formed by changes in sea level during the Late Quaternary. The