The importance of fundamental soil sampling method

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ABSTRACT: The boring survey is the most fundamental technology of the ground survey, such as drilling the ground, directly investigating the in-situ physical properties of the ground and collecting samples for soil test. Especially, the technique of collecting samples with undisturbed condition is important, so if the disturbance becomes larger at the time of sampling, the strength of the ground will be underestimated. Sampling of sand and gravel is often used with a rotary triple-tube sampler, but there are many discussions about its quality. In this report, we first consider the applicability of the sampling method standardized by the Japanese Geotechnical Society for sand and gravel. After that, we take up a new sampling technique for sand and gravel which is difficult to collect by standardized sampling method and summarize the structure and characteristics of the sampler. In addition, we evaluate the sample quality and show the effectiveness of this sampling technique.

Keywords: sample quality, undisturbed sample, coarse-grained soil, soil property

1. Introduction

The boring survey, which involves the excavation of the ground to conduct in-situ investigation of the physical properties of a given site through load testing, physical well-logging, sounding tests or through sampling the ground to collect samples for soil test, is the most fundamental of the techniques used in ground investigation. The sampling technique in which undisturbed samples are collected through boring is particularly important: If the soil is disturbed in the sampling process, it is possible to underestimate the ground strength and its deformation characteristics, which in turn could lead to an over-design of the civil engineering structure, and cause the entire project to become uneconomical.

This paper will focus on sampling sand and gravel soil, which are difficult to collect without disturbing and demonstrate that the application of the currently standardized sampling technique in Japan is difficult. After which, an overview of a new sampling technique (GS sampling [1]) developed for sand and gravel soil will be explained and evaluate the quality of the samples collected through this sampling method.

2. Sampling methods standardized in Japan and the application issues for sand and course-grained ground

The structure of samplers standardized in The Japanese Geotechnical Society and its relationship with applicable grounds is indicated in Table 1 [2]. Till now, a fixed-piston type thin wall sampler or a rotary triple-tube sampler was used to obtain undisturbed samples of sand and coarse-grained soil. The former collects samples by inserting a sharp-edged stainless-steel tube into the ground but when sand and gravel grains hit the edge of the sampling tube, it will stop penetration as well as making a disturbance in the sample. The typical case is shown in Fig. 1. In many cases, when the ground is even looser, there will be drop-outs in the sample even if penetration has been achieved. The latter sampler is a rotary type, with its outer tube cutting the ground by rotation, to push the ground into the inner tube to obtain the sample. Even in this method, the tip of the inner tube protrudes further than the outer tube and causes similar problems as the former sampler. As indicated here, it has been difficult to obtain samples of undisturbed sand and coarse-grained soil using conventional samplers.

Table 1. Relationship between structure of standardized sampler and applicable grounds.

Method for sampling		Sampling category	Structure	Type of ground										
				Clay			Sand			Sand gravel		Rock		
				Soft	Middle	Stiff	Loose	Middle	Dense	Loose	Dense	Soft rock	Medium-hard rock	Hard rock
				N-value										
				0～4	4～8	＞8	＜10	10～30	＞30	＜30	＞30			
Thin-walled tube sampler with fixed piston	Hydraulic system	A	Single tube	◎	◎	○	○							
	Extension system	A	〃	◎	○		○							
Rotary double-tube sampler		A	Dubble tube		◎	○								
Rotary triple-tube sampler		A	Triple tube		◎	◎	○	◎	◎		○			
Rotary double-tube sampler with sleeve		A,B	Dubble tube	○	○	○	○	○	○	○	○	◎	◎	◎
soil block samples		A	-	◎	◎	◎	○	○	◎		○	○		
Rotary tube sampling for sofft rock		A	Multiple tube			○						◎	○	
◎Suitable ○Applicable														

Figure 1. Damage of sharp-edge of a fixed-piston type thin wall sampler

3. A new sampling method called GS sampler for collecting sand and course-grained soil

This time, GS sampler has been developed as a sampler for use on sand and coarse-grained soil. The construction of GS sampler is as indicated in Fig. 2, and consists of an outer tube and an inner tube with a fixed piston installed inside. The sampler head is divided into the inner tube head and the outer tube head, and structured so that the rotation of the outer tube will not be transmitted to the inner tube. The inner tube is made out of transparent acrylic tube and the interior of the inner tube is kept at a vacuum by a fixed piston, similar to the thin-walled tube sampler with fixed piston, to prevent the drop-out of the sample. The intermediate rod (= the axis of the piston: hexagonal cross section) is extended to the turret on the top of the boring machine, and fixed to securely prevent it from co-rotating. In addition, an outlet for recirculating water is provided on the sides of the bit, so that the water feed pressure of cutting water will not directly affect the ground at the tip of the bit. An O-ring is provided in a groove made on the inner tube tip shoe (metal fitting tip) to cut off water from the gap with the outer tube, not to let recirculating water to flow into the inner tube-side from the tip of the inner tube.

The merit of GS sampler and its sampling are, a) Samples are obtained in a transparent acrylic tube, allowing immediate observation of the sample after they have been taken. b) It can be applied for various soils, such as waste matters, weathered rocks, and fractured zones, in addition to cohesive soil, sandy soil, and gravel soil. c) Because a hexagonal intermediate rod is used, for example, if a point on the hexagon is secured pointing exactly North, a North fixed directional sampling will become possible. It will contribute to estimating the incline of the strata. d) Both dry and wet sampling is possible, allowing mud water, bubbles, compressed air, etc. to be used. The shortcomings are a) The set-up of the sampler will require some additional time, for the securing of the intermediate rod, etc. b) It will become costlier than the rotary-type triple-tube sampler, etc. for its work procedures and material costs. c) Will require skills for adjustments to match the soil characteristics in its assembly and adjustment in thrust velocity when sampling.

4. The appearance and X-ray images of minimally disturbed samples introduction

We examined the quality of the undisturbed samples collected through GS sampling from three areas across Japan (i.e., Katori City, Chiba Prefecture; Chubu Region: Aichi Prefecture, Mie Prefecture, and Gifu Prefecture; Miyako City, Okinawa Prefecture) as shown in Fig. 3. The types of soil that were selected for this examination were: alluvial sandy soil in Katori City, Chiba Prefecture; the embankments of sand and gravel soils in the Chubu region (Aichi Prefecture, Mie Prefecture, and Gifu Prefecture); and coral gravel soil in Miyako City, Okinawa Prefecture.

The top three meters of the ground surface layer in Katori City, Chiba Prefecture, is made up of soft alluvial clay and the composition below that is comprised of alluvial sandy soil. The alluvial sandy soil is primarily comprised of fine sand with uniform particle size with the N value of approximately 5 to 20. For GS sampling, nine undisturbed samples from the depth direction were collected, and the sample recovery rate was at nearly 100%. Normal slurry was used when sampling. The X-ray images of the collected samples are shown in Fig. 4. Based

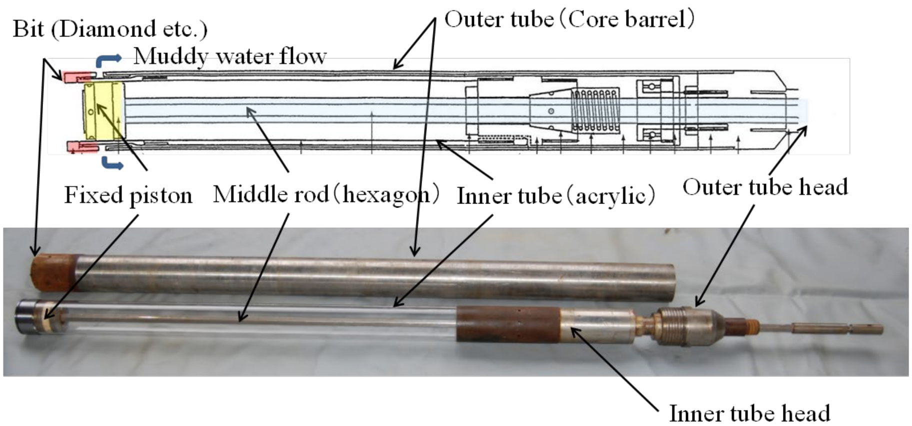

Figure 2. Structure of GS sampler.

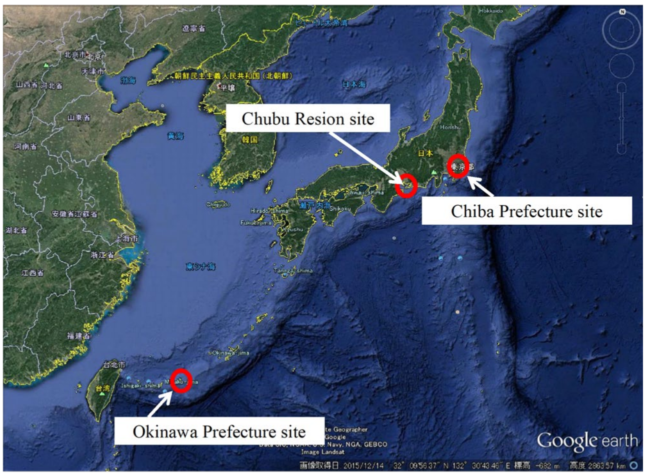

Figure 3. Investigation site map

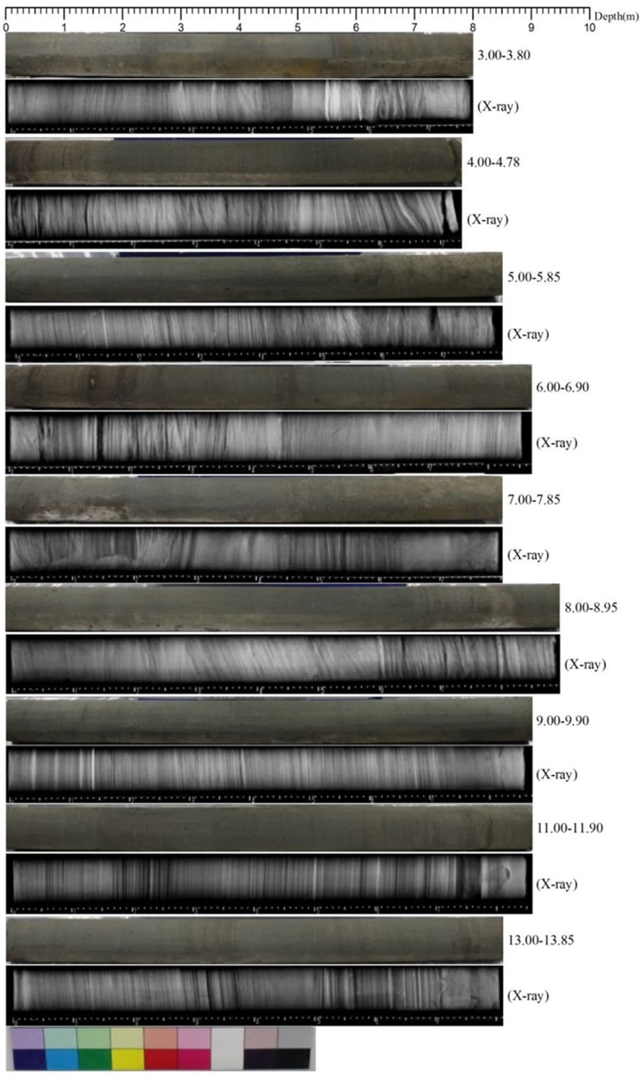

Figure 4. X-ray photograph of undisturbed sandy soil (Chiba Prefecture site)

on the X-ray images, there were no cracks or other issues associated with disturbance caused by sampling. Rather, excellent samples with striped structures which indicate the alluvial sandy soil sedimentation condition was clearly visible were collected.

In the Chubu region, several embankments of sand and gravel soil from around the region were made the subject

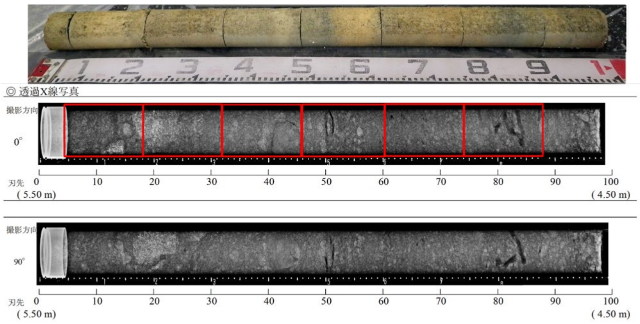

Figure 5. X-ray photograph of undisturbed gravel soil (Chubu Resion site: Red line shows the cutting part for soil test)

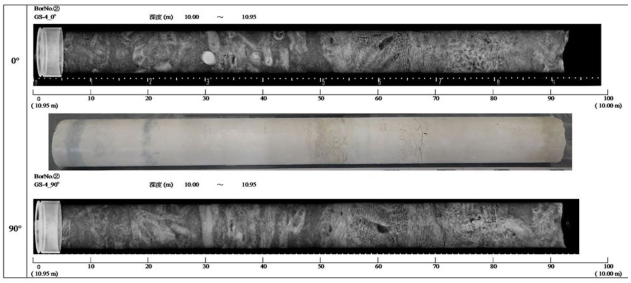

Figure 6. X-ray photograph of undisturbed coral gravel soil (Okinawa Prefecture site)

for conducting GS sampling for the collection of undisturbed samples. These embankment materials are assumed to be the result of cutwork near the targeted area, and several of the areas contained gravel and cobblestones. While conducting GS sampling, sufficient sample length necessary for conducting the tests were collected for the most part, but with the parts where there was a lot of mixed gravel that were rather loosely packed, the sample recovery rate had slightly reduced. The collection time per sample was approximately two to three hours. The excavation fluid used in the sampling was polymer slurry. The exterior and X-ray images of the collected samples by way of GS sampling are shown in Fig. 5. While the samples shown in the photo is that of gravel soil that contains 48 % gravel fraction and 24% fine fraction, during sampling the mixed gravel was cut resulting in obtaining excellent samples.

The marine soil of the Ryukyu Islands which Miyako City, Okinawa Prefecture is located has both hard grounds akin to a limestone layer made up of modern coral reefs and coral carcasses and alluvial soft ground. The alluvial soft ground is generally called coral gravel soil, contains a large amount of branch coral gravel, and fine-grained soil loosely fills the gaps between branch coral gravel. Minimally disturbed samples were collected from the coral gravel soil at the seabed of Hirara Port of Miyako City at the water depth of approximately 10 meters, using the GS sampler. The coral gravel soil of this area can be generally divided into two kinds: sandy soil that is mostly made up of fine to medium sand with occasional coral gravel, and gravel soil that is primarily made up of silty fine sand which contains coral gravel of approximately 40 to 50mm in diameter. The *N*-value is around 20 for the sandy soil, while the gravel soil is approximately 10 to 30 though it varies quite a bit. Of this coral gravel soil, eight samples of sandy soil and 14 samples of gravel soil were collected. For sampling, the ordinary slurry was used. The collection time per sample took approximately two to three hours, but the sample recovery rate was pretty much at 100%. The exterior and X-ray images of the collected samples are shown in Fig. 6. While from the photographs we can observe that the samples contain many branch corals, since we do not see any gaps around it, we can conclude that the coral gravel did not move during sample collection and no matrix had leaked. Thus, we can say the sampling was excellent.

5. Quality evaluation of the samples based on the soil test findings of the collected undisturbed samples

In Katori City, Chiba Prefecture, we conducted cyclic triaxial tests to determine the deformation characteristics of the geomaterial using the undisturbed samples of alluvial sandy soil. The relation between the shear modulus of rigidity obtained through testing and the shear modulus of rigidity determined through PS logging which was conducted at the same boring location as where the sampling took place is shown in Fig. 7. It should also be noted that in Fig. 7 similar findings based on the same tests conducted in the Kansai Area is added as well [3]. According to these findings, the values of both are at approximately 1:1. While this may have been from limited test findings, if we are to consider that PS logging is indicating the shear modulus of rigidity of the original ground, then we can determine the quality of the samples from GS sampling is in excellent condition that is approximately equivalent of the original ground.

With the Chubu region, we used the undisturbed samples if the sand and gravel soil of the embankments to conduct triaxial compression (CUB) tests. To determine the difference in the sample qualities according to the different sampling methods, we conducted triaxial compression tests which used samples collected from the same location using the GS sampler as well as the rotary triple-tube sampler and compared; the findings of the comparison are displayed in Fig. 8. According to these findings, samples collected using GS sampling clearly showed the angle of shear resistance to be three to five degrees greater than those samples collected using the rotary triple-tube sampler. The angle of shear resistance that is obtained from triaxial compression tests is typically shown to be smaller the greater the sampling disturbance is, which indicates that the samples collected through the GS sampler are clearly of higher quality than those collected through the rotary triple-tube sampler.

In Miyako City, Okinawa Prefecture, the triaxial compression (CUB) test was conducted using the undisturbed samples collected with the GS sampler, and the findings are shown in Table 2. In this table, the estimated angle of shear resistance from the N-value using the method described in the Technical Standards and Commentaries for Port and Harbour Facilities in Japan are listed as well [4].

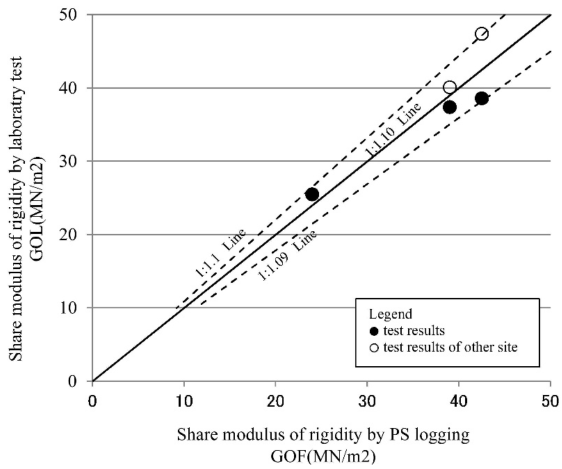

Figure 7. Comparison of shear modulus obtained from laboratory test and PS logging

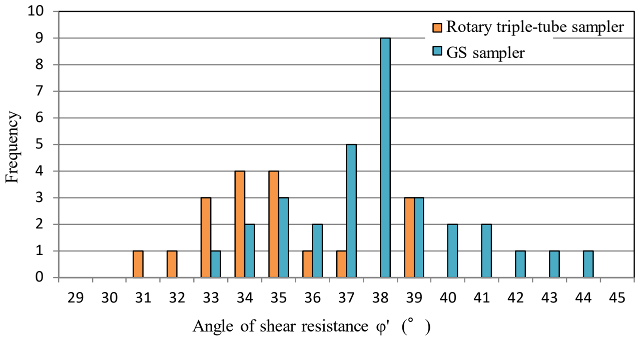

Figure 8. Comparison of angle of shear resistance by sampling method

While the average angle of shear resistance of the sandy soil layer estimated from the N-value was φ=37.4°, the triaxial compression test results

were on average φ=43.0°. Furthermore, while the sand gravel layer, the average angle of shear resistance estimated from the N-value was φ=36.5°, the results of the triaxial compression test shown an extremely large value at an average of φ=60.0°. In this way, it was found that if the angle of shear resistance of coral gravel soil is estimated using the N-value and φ equation that is typically used on sandy soil will lead to underestimation. The reason form this is most likely due to the surface roughness of the coral pieces; as they grind against each other, their shear resistance becomes greater.

6. Conclusions

We applied the GS sampler—which was developed for sand and gravel soil sample collection that was difficult to do with the conventional method—to alluvial sandy soil found in Katori City, Chiba Prefecture, the sand and gravel soil embankments of Chubu region, and coral gravel soil found in Miyako City, Okinawa Prefecture. The findings can be summarized as the following:

With the alluvial sandy soil of Katori City, Chiba Prefecture, the sample recovery rate was 100%. The sand

Table 2. Comparison of angle of shear resistance obtained from laboratory test and standard penetration test

Soil type	Angle of shear resistance φ(°)	
	Presumption by standerd penetration test (N value)	Result of triaxial compression test
Sandy soil	Avarage 37.4	38.0～47.9(Avarage 43.0)
Sand gravel	Avarage 36.5	38.3～81.61(Avarage 60.0)

and gravel soil embankments of Chubu region and the coral gravel soil of Miyako City, Okinawa Prefecture had some dropout of samples where a great amount of gravel was present, or where the soil was extremely loose, but for the rest of the sections the sample recovery rate was nearly at 100%.

Based on the observation of the exterior images as well as the X-ray images of the collected samples, the gravel that had been contained were properly cut, there was no disturbance with the matrix either, and we can determine that these samples are qualitatively excellent samples.

The mechanical test results of the collected samples showed there was hardly any difference between the modulus of rigidity of the GS sampled materials and the modulus of rigidity of the original ground. When it comes to the triaxial compression test results, the samples collected using the GS sampler showed larger figures than those samples collected using the rotary triple-tube sampler. The angle of shear resistance of the samples taken from testing the GS sampler in triaxial compression test results shows greater strength than when the angle of shear resistance is estimated using the *N*-value.

Based on the above findings, we can conclude that the quality of the undisturbed samples collected through GS sampling is high, and by effectively using GS sampling going forward, it will become possible to offer accurate mechanical test results of sand and gravel soil, and as a result, it will become possible to draw up basic designs for economical structures which would contribute to the reduction of the total construction cost and expenses.

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