

Estimation of Sample Quality and Liquefaction Characteristics of Loose Sand

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ABSTRACT

An investigation was carried out to estimate liquefaction characteristics in Katori city, Chiba prefecture, where liquefaction damage occurred due to the Great East Japan Earthquake. Since it was important to obtain high quality samples for estimating correct liquefaction characteristics of loose sand deposits, a specific sampler called ‘GS sampler’ was used. In order to confirm sample quality, the appearance of the samples was visually checked and X-ray observation was carried out. As the results of the observation, the samples collected using the GS sampler were in good quality. Furthermore, the results of modulus of rigidity in a small strain area, G_0 , obtained by a cyclic test to determine deformation properties were almost the same as the results of G_0 obtained by a PS logging. It means that the samples obtained by the GS sampler were in good quality for mechanical soil tests. The results of liquefaction resistance, R_L , obtained by a cyclic triaxial test were almost the same as the results of R_L calculated based on specifications for highway bridges using N value and a fine-grain fraction content ‘ F_c ’. However, the both results were a little bit different in the case of very loose sand layer which deposited near the surface ground. One of the reasons that may be considered is the recent development of a cyclic triaxial test device that enables detailed liquefaction estimation for very loose sand.

Introduction



Photo 1. Scope of Sawara dry riverbed

Note) Trace of sand boiling has been seen entire riverbed surface

The Tohoku Region Pacific Coast Earthquake caused liquefaction, which resulted in extensive

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damage on houses along the Tokyo Bay coastal area and the Tone river (the Japanese Geotechnical Society, 2011). It was the artificial ground where the liquefaction damage intensified, including the seaside areas, former river channels and lakes. Furthermore, liquefaction occurred in the natural ground such as the alluvial plain along the Tone river as well (Wakamatsu and Sakina, 2013). We conducted a field experiment at the Sawara dry riverbed of the Tone river. The Sawara dry riverbed consists of the dredged land area of the Tone river and the natural ground area of the alluvial plain. Sand boiling due to liquefaction occurred over the entire surface of this site as shown in Photo 1. This paper presents the sample quality obtained by a new sampler called GS sampler and liquefaction characteristics in the natural ground area of the alluvial plain (Atec Yoshimura Co., LTD, 2015).

Site of Field Experiment (Sawara Dry Riverbed)

We conducted a field experiment for examining the sample quality and liquefaction phenomena at the Sawara dry riverbed of the Tone river. As I mentioned before, the terrain of this site can be divided into two areas: the dredged land area and the natural ground area. Previously, the northwest side of this site was sandbank in the stream, as shown in Figure 1. The southeast side, where there had been a flow path of the Tone river in 1903, was landfilled in 1967. The field experiment was carried out at the northwest side, where natural alluvial soil is distributed.



Figure 1. Map of experimental site (Topographic map in 1903)

Results of Boring Exploration and Test for Physical Properties

We carried out boring exploration in two stages. At first stage, a standard penetration test at intervals of 0.5 m in depth and seismic velocity logging at intervals of 1 m were conducted. At next stage, we collected undisturbed samples for soil tests. The results of the standard penetration test and seismic velocity logging are shown in Figure 2.

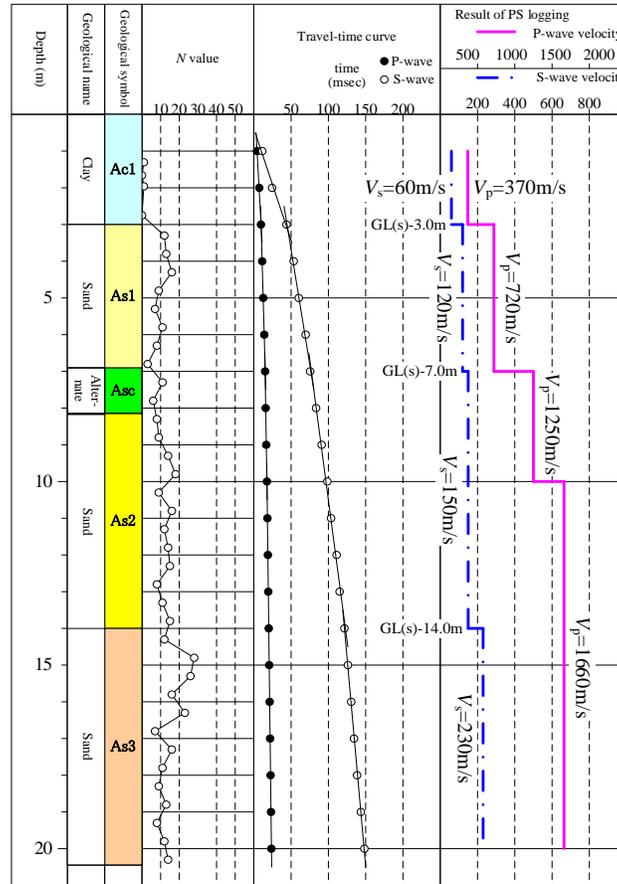


Figure 2. Result of boring exploration and PS logging

We found that an alluvial clay layer, Ac, and sand layers, As1, As2 and As3, were distributed in this area. Ac layer was distributed from the earth surface to 3 m in depth. Ac layer was very soft because N value was 1 to 0 and seismic velocity, V_s , was 60 m/s. Ac layer and the sand layers were distributed to 20 m in depth. The alternation of strata, Asc, was composed of sand and clay layers.

We carried out a test for physical properties and an unconfined compression test for Ac layer using the undisturbed samples obtained by a thin-walled tube sampler with a stationary piston. Ac layer was mainly composed of fine-grained fraction. The clay fraction was 39% to 31%, the silt fraction was 62% to 54% and the sand fraction was 14% to 7%. In addition, the liquid limit, w_L , was 72% to 64%, the plastic limit, w_P , was 37% to 29% and the natural water content, w_n , was 73% to 55%. Ac layer was very soft soil since the natural water content was close to the liquid limit and the unconfined strength, q_u , was 53 kN/m² from 40 kN/m². The grain size distribution curves of As1, Asc, As2 and As3, are shown in Figure 3. Since these curves of sand layers are very steep and are not vary, the sand layers are almost uniformity. The content of fine-grained fraction was 20% to 5%, and water content was 40% to 30%. In addition, N value was 25 to 5 and seismic velocity was 230 m/s to 120 m/s. These values had a tendency to increase gradually to the depth. Asc consisted of sandy silt part and sand part. Groundwater level was confirmed to a depth of 1.5 m

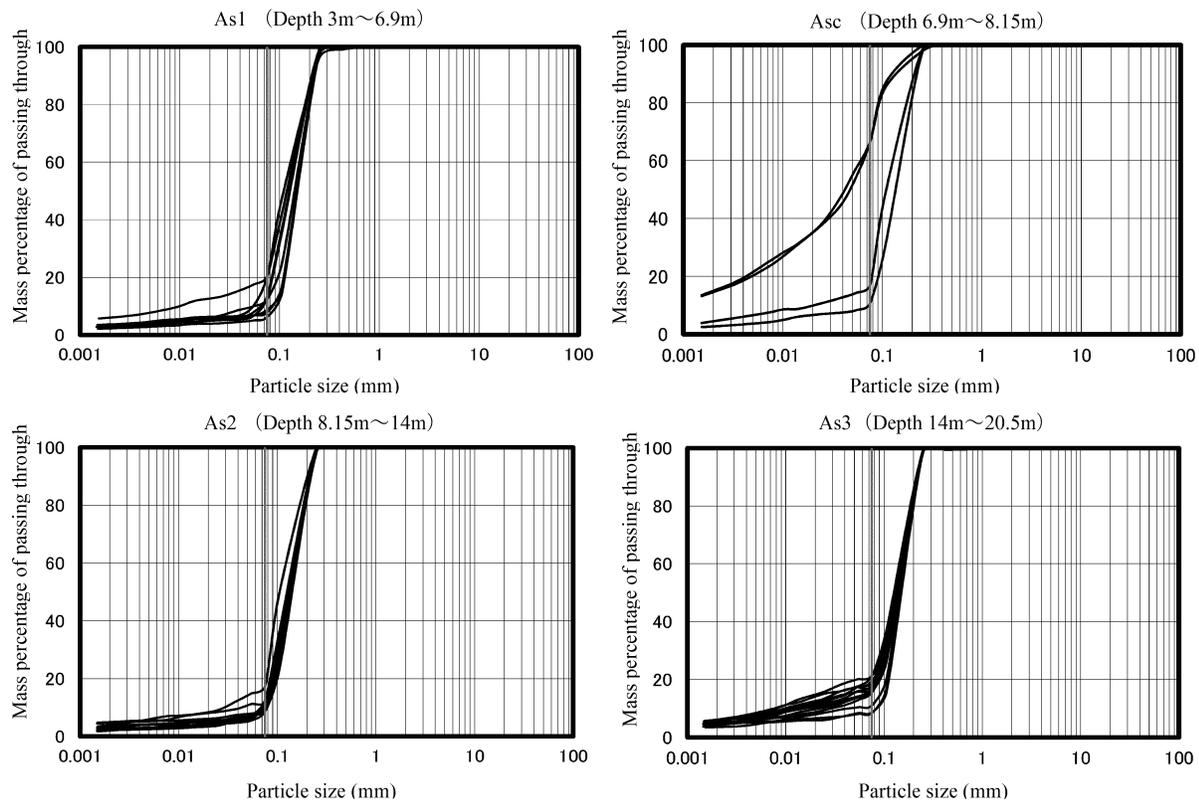


Figure 3. Result of grainsize analysis

Undisturbed Sampling for Alluvial Sand (GS Sampling)

The new type soil sampler called GS sampler shown in Figure 4 was used for collecting undisturbed alluvial sand samples. GS sampler is a high-quality sampler for collecting good samples in undisturbed condition from loose sandy soil, gravel, fractured zone and waste matter which are very difficult to obtain such good samples. GS sampler has some structural features. Firstly, drilling fluid such as muddy water, bubbles and air can be used for protecting the borehole wall at the time of sampling. The drilling fluid is circulated just above the sampler tip and does not directly contact with the tip. As a consequence, the samples can be collected without outflow. Secondary, a stationary piston is set in the sampler in order to prevent the co-rotation and falling of the samples. Finally, the samples are stored in an acrylic transparent tube in order to see the sample condition in the field. GS sampling is excellent technology, but on the other hand, the cost is expensive compared with usual rotary triple-tube sampling. However, it is quite cheap compared with a freezing sampling method.

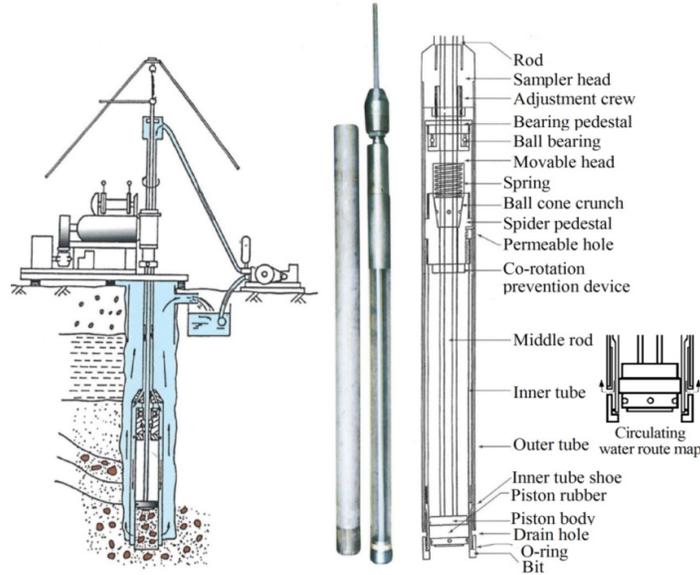


Figure 4. Structure of GS sampler

In this experiment, nine undisturbed samples were collected from As1, As2, As3 and Asc layers using the GS sampler. The collecting rate of samples is almost 100%. All the photos of outward appearance and an X-ray photograph are shown in Photo 2. There are no cracks and disturbance of the samples and can see the sedimentary structure of the sand layer. Thus, the sample quality obtained by the GS sampler is considered in good condition.

Dynamic Strength Characteristics of Alluvial Sand

A cyclic triaxial test was carried out for alluvial sand, As1, As2 and Asc layers, using the samples obtained by the GS sampler. The test result which is the relationship between the number of loading cycles, N_c , and cyclic stress amplitude ratio, $\sigma_d/2\sigma'_0$, is shown in Figure 5. The liquefaction resistance ratio, R_{L20} , obtained by the cyclic triaxial test, N value by the standard penetration test and a fine-grained fraction, F_c , by grain size analysis are shown in Figure 6. R_{L20} of the sand layers is in the range of 0.15 to 0.26, which is a small value. The average of R_{L20} of As2 is bigger than R_{L20} of As1 and Asc layers.

The liquefaction resistance ratio, R_{L20} , obtained by the cyclic triaxial test and the liquefaction resistance ratio, R_L , calculated using N value and F_c based on 'Specification for Highway bridges (May, 2012)' are shown in Figure 7. In As1 layer, R_{L20} is a little smaller than R_L . However, the both results, R_{L20} and R_L , are approximately equal in Asc and As2 layers. While R_L of As1 layer is approximately equal to R_L of As2 layer, R_{L20} of As2 is bigger than R_{L20} of As1. N value of As1 and As2 layers shown in Figure 2 are almost the same. In contrast, V_s obtained by a PS logging of As2, $V_s=150$ m/s, is greater than the one of As1, $V_s=120$ m/s. The trend of V_s is the same as the trend of R_{L20} .

Therefore, it is possible to point out that R_L calculated using N value and F_c of As1 may be underestimated than the actual value.

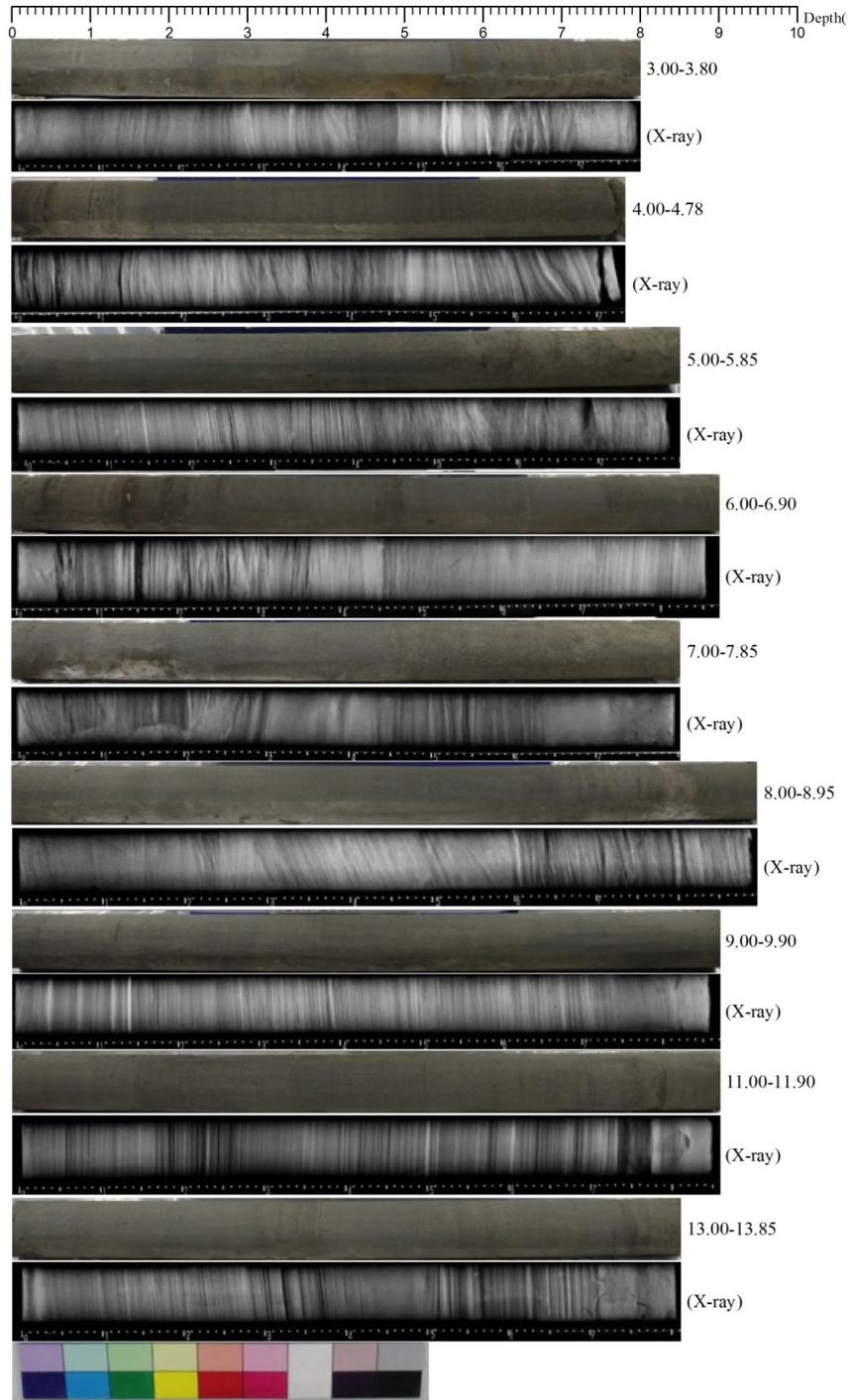


Photo 2. Outward appearance picture and X-ray photograph of the samples

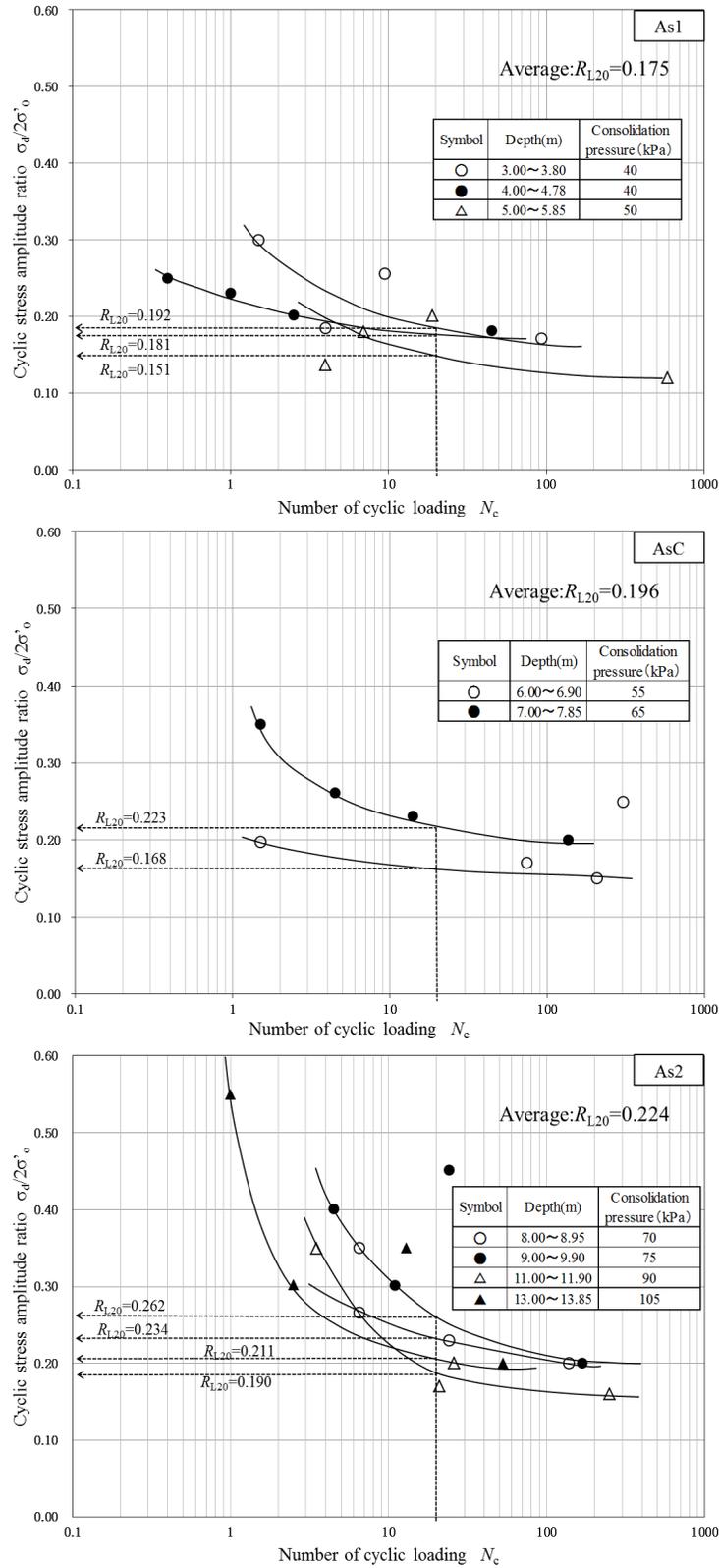


Figure 5. Results of cyclic triaxial test

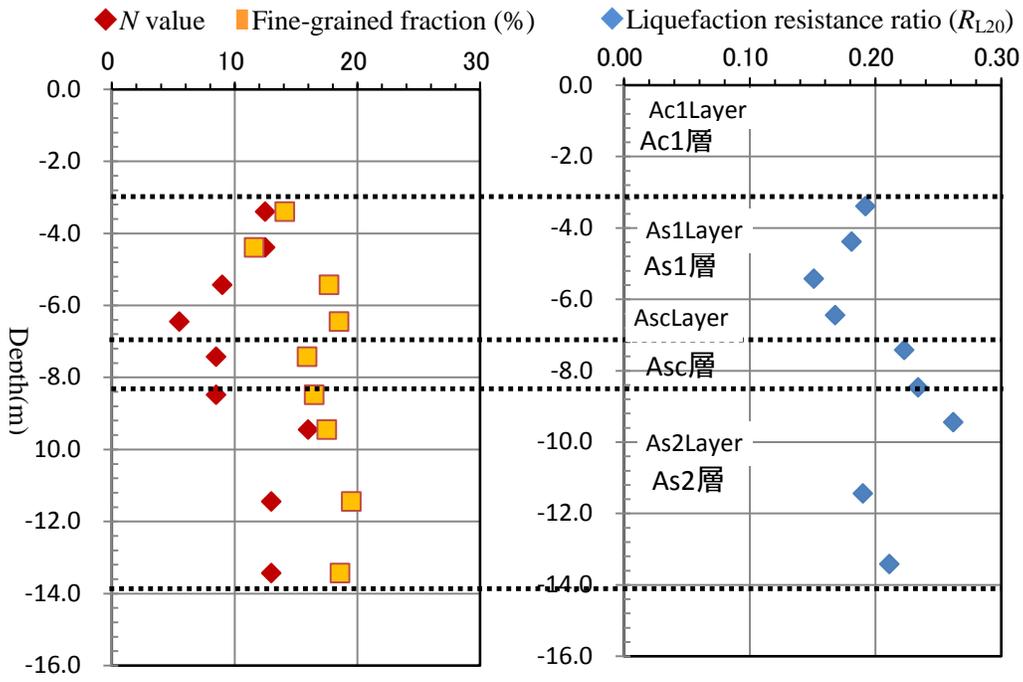


Figure 6. Relationship between liquefaction resistance ratio obtained by cyclic triaxial test, N value and fine-grained fraction

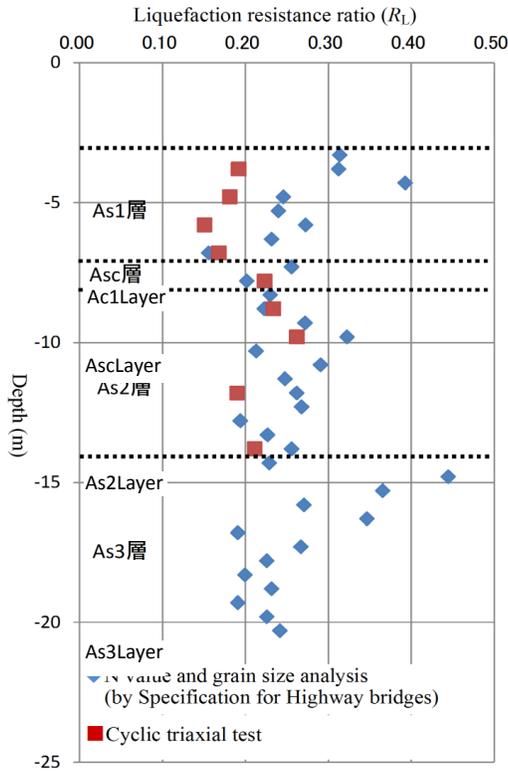


Figure 7. Comparison of liquefaction resistance

Discussions

The result of the cyclic triaxial test to determine deformation properties of geomaterials using the samples collected by the GS sampler is shown in Figure 8. The relationship between the initial shear modulus, G_0 , obtained by the cyclic triaxial test and the one calculated by the result of the PS logging is shown in Figure 9, to which other site data are added (Hirai et al., 2015). While there are only five pieces of data, both values are almost the same. The sample quality obtained by the GS sampler can be estimated to be in good condition because G_0 calculated by the PS logging is regarded as the original in-situ initial shear modulus.

A surface wave exploration was carried out at four survey lines around the boring point in order to perform a comparison with the result of the PS logging. The typical results are shown in Figure 10. The low velocity zone, whose V_s is from 70 to 100 m/s corresponds to the alluvium clay layer above 3 m in depth. Alluvium sand exists deeper than 3 m in depth. The strata were nearly horizontal in the range of the survey line.

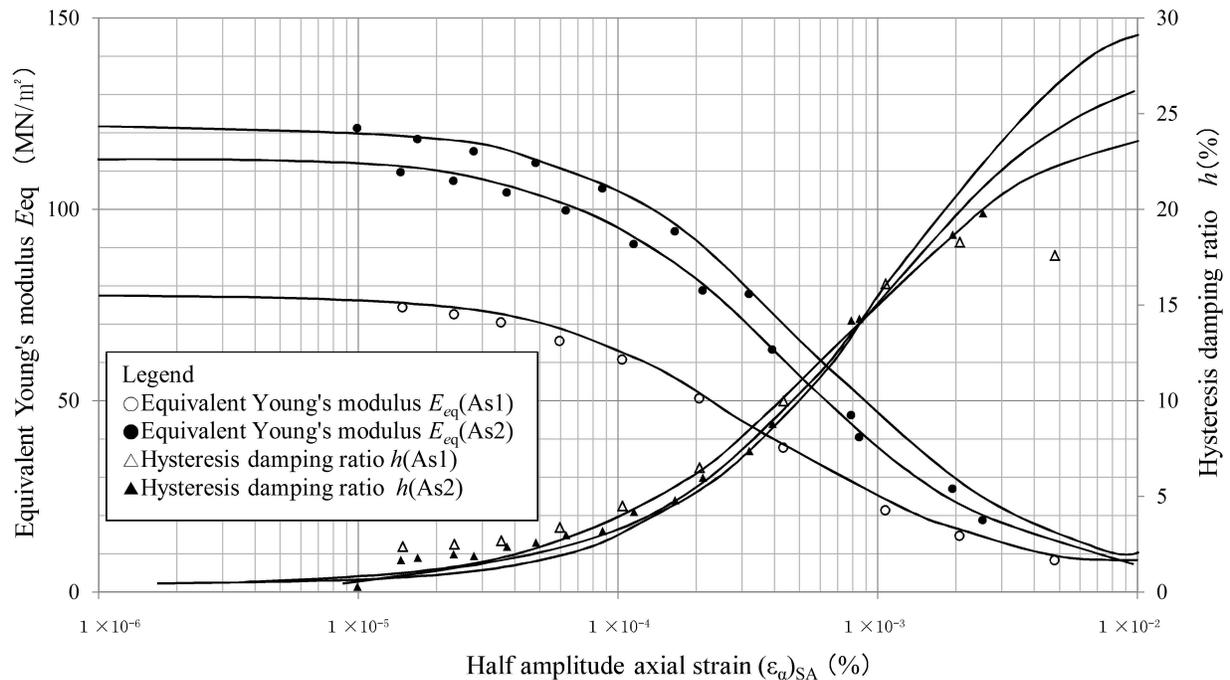


Figure 8. Result of cyclic triaxial test to determine deformation properties of geomaterials

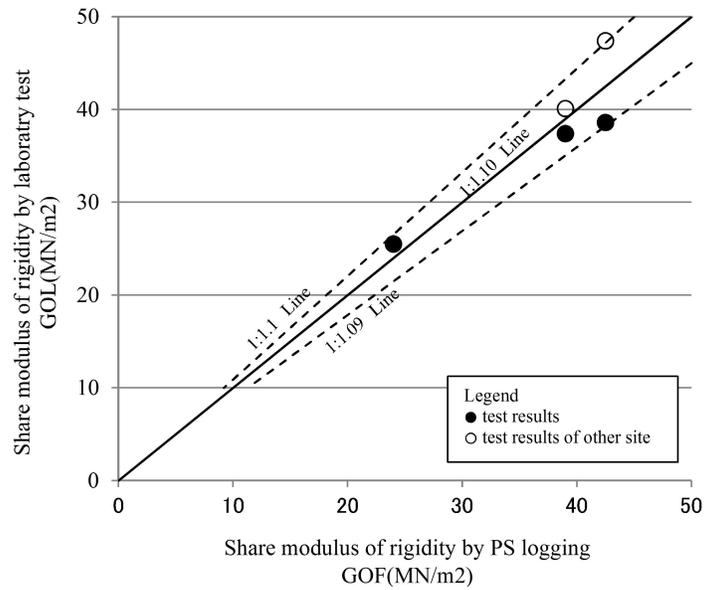


Figure 9. Comparison of initial shear modulus

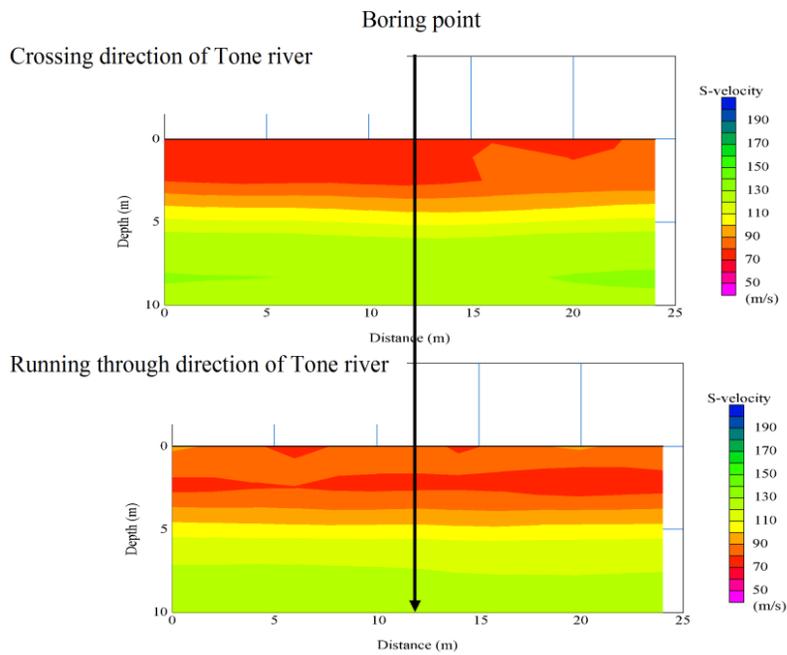


Figure 10. Results of surface wave explorer

Conclusions

Large scale sand boiling occurred at the Sawara dry riverbed due to the Tohoku Region Pacific Coast Earthquake. A new type soil sampler called GS sampler was used for collecting undisturbed alluvial sand samples in this site. The sample quality obtained by the GS sampler can be estimated to be in good condition because the initial shear modulus, G_0 , obtained by a cyclic triaxial test using the samples obtained by the GS sampler and the one calculated by the

result of the PS logging which is regarded as the original in-situ initial shear modulus are almost the same.

We examined the liquefaction characteristics of natural alluvial soil distributed in this site. Consequently, it was confirmed that the alluvial sand layer tended to be easily liquefied because this layer consisted of uniform sand and liquefaction resistance ratio, R_{L20} , was a small value, which is 0.26 to 0.15.

Extensive damage on houses occurred not only in the dredged land area but also the natural alluvial ground area along the Tone river. The same investigation like this paper has been carried out in Inashiki city and Katori city in Ibaraki prefecture. We are going to promote the research for clarifying the liquefaction characteristics of natural alluvial soil using these data.

Acknowledgement

For using the Sawara riverbed for this field experiment, we have received the cooperation of Tonegawa-Karyu River Office of Kanto Regional Bureau of Ministry of Land, Infrastructure, Transport and Tourism and Katori city in Chiba prefecture. This experiment has been supported by the research promotion from Ministry of Land, Infrastructure, Transport and Tourism. We would like to express our gratitude to all supporters of this experiment.

References

Atec Yoshimura Co., LTD. <http://www.atec-y.co.jp/>, 2015.

The Japanese Geotechnical Society. *Reality explication of liquefaction phenomenon in Kanto area by the 2011 off the Pacific coast of Tohoku Earthquake*, Report by Ministry of Land, Infrastructure, Transport and Tourism 2011.

Hirai K, Kiku H, Ohshima A, Rito F. Collecting undisturbed sample for difficult condition soil (GS sampling), *Geotechnical Engineering Magazine* 2015; Vol. **63**(4) Ser. No. 687.

Wakamatsu K, Sakina S. The liquefaction by the Tohoku Region Pacific Coast Earthquake and past liquefaction history. *Tishitu-to- Chosa*, 2013; **138**: 6-11.