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Dynamic Penetration Test with Measurement of Pull Out Resistance

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ABSTRACT

The cone penetration test is one of the most important and convenient tools for soil investigations. In recent decades, many efforts have been made to extend its applications to various fields in geotechnical engineering. This paper presents a newly developed dynamic cone penetration test with measurement of the pull-out resistance, which is named "Penetration & Pull-out Test (PPT)". The PPT measures the dynamic penetration test and quasi-static pull-out resistance. "*N*-value", the number of blows for penetration into soil under the undrained condition is measured from the dynamic penetration test, while the friction resistance of soil under the drained condition is measured from the quasi-static pull-out test. Validation test results indicate that PPT is highly useful for identification of liquefaction-induced problems. PPT is a robust device because it is has no electrical sensor at the tip of the cone. In addition, liquefaction risks such as the factor of safety can be evaluated from PPT in a short time. Therefore, liquefaction risks for a large area can be evaluated in a relatively short period. As the future direction of this study, we will develop a more economical and simpler in-situ apparatus for estimating the liquefaction susceptibility of soils.

Introduction

Many case histories on earthquake disasters have shown that significant damage occurs in soft ground around coastal urban areas in Japan due to the soil liquefaction. At present, the liquefaction potential can be evaluated only at limited points because the estimation of liquefaction susceptibility requires detailed data from laboratory cyclic loading tests on undisturbed samples.

In particular, the liquefaction susceptibility in an area is based on sparse data. Past investigations on earthquake damages indicate, on the other hand, that degree of damage often varies significantly even in a small area. Therefore, a more precise evaluation is required for the reliable design against soil liquefaction.

Past studies on soil liquefaction problems have focused mainly on the liquefaction resistance from the laboratory tests, while there have been few studies on in-situ estimation of the liquefaction potential. There has some research using the Piezo Drive Cone (PDC) proposed by Sawada (2009). However the investigation cost is relatively high, because the PDC uses a high performance pressure transducer.

Dynamic penetration tests such as PDC, have been used in Japan because of good correlation with laboratory undrained cyclic strength data.

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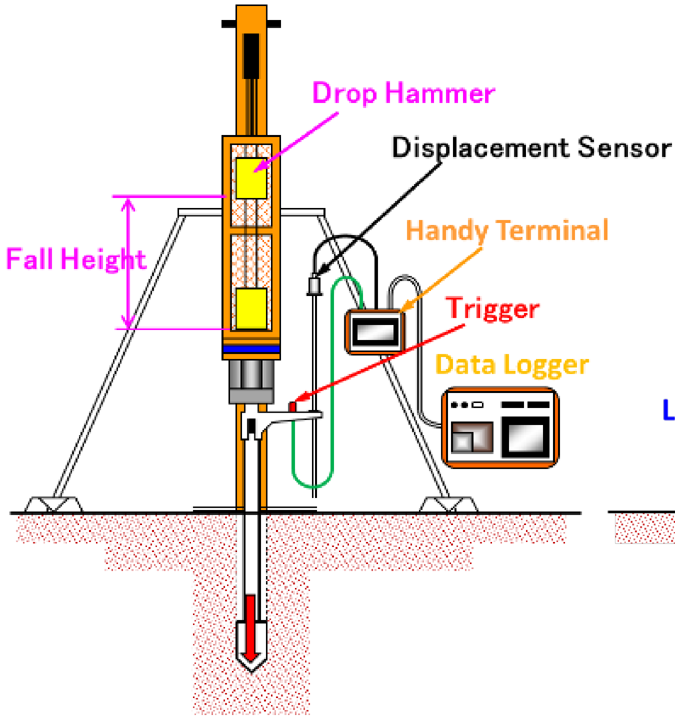
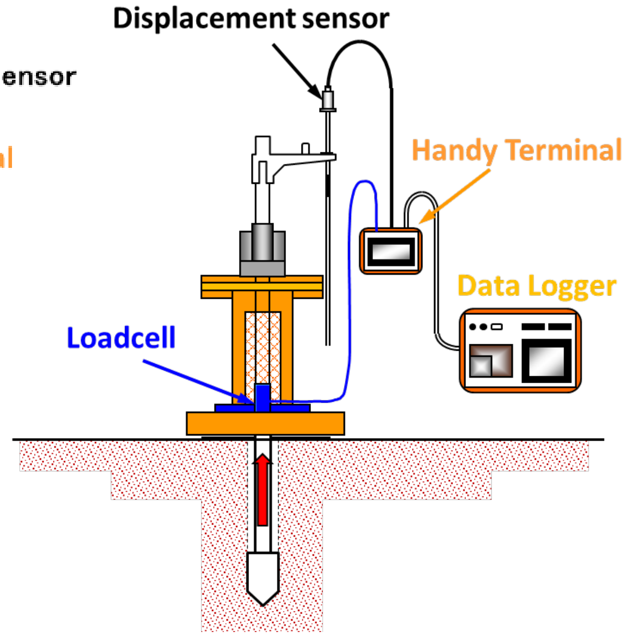


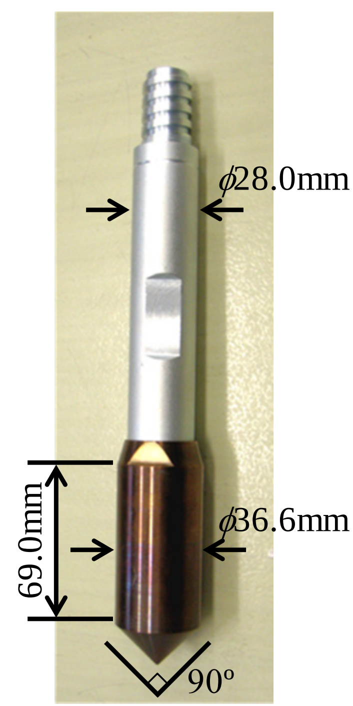
(a) Dynamic Penetration Test



(b) Quasi-static Pull out Test

Figure 1. Penetration & Pull-out Test (PPT)

(a) Dynamic Penetration Test



(b) Cone apex

Figure 2. View of Penetration & Pull out Test (PPT) in field

Test Equipment and Procedures

Figure 1 shows a schematic figure of the dynamic penetration test with measurement of the pull-out resistance, proposed in this paper, which is named "Penetration & Pull-out Test (PPT)" . This system consists of the dynamic penetration test and the pull-out resistance test.

A light-weight dynamic penetration device which is named "Mini Ram Sounding (MRS)" is modified from the Swedish Ram Sounding test equipment. The sounding rods are 28 mm in diameter. The PPT-cone is 36.6 mm in diameter, 69 mm in length and 90 degree in apex angle. The penetration rods are driven down mechanically by a 30 kg hammer with free fall from the height of 35 cm. The penetration resistance is defined as the number of blow counts (N_m) required to drive the penetrometer 20 cm downwards assumed to be under the undrained conditions. SPT N-values (N_{spt}) are equal to a half of these blow counts (N_m) as follows,

$$N_{spt} = 1/2\ N_m \tag{1}$$

The MRS system can be easily brought into the fields without a vehicle and can be set up within 5 minutes. The dynamic penetration can be automatically driven by a hydraulic motor. Figure 2 shows the view of PPT-system during the dynamic penetration test in the field. The efficacy of this dynamic penetration method was mentioned by Ito et al. (2002) and Hasegawa et al. (2003).

The PPT system consists of the dynamic penetration equipment such as displacement sensor, triggering sensor, pull-out equipment with load cells for pull-out resistance, "handy" terminal and data logger.

Displacement Sensor

A non-contact magnetostrictive transducer is used as the displacement sensor in the system. The depth of the cone tip is derived from the displacement of the top of sounding rod relative to the fixed point at the base of the equipment. The data acquisition system records only penetration displacements at the ground surface during the dynamic penetration.

Trigger

The proximity sensor at the anvil is used to trigger data recording. The trigger signals are transmitted via an electrical cable through the "handy" terminal to the data logger.

Pull-out Equipment

A view of the newly developed pull-out equipment is shown in Figure 3. The pull-out resistance is measured between the center rod clamp and two hydraulic cylinders. Two sets of load cells correct for any eccentric loading through bridge circuits. Because any impact load does not arise during the quasi static pull-out operation, high-precision static strain gauges are used for the load cells. The up-and-down motion of the hydraulic cylinders changes to the opposite direction when the stroke limit is reached. When the hydraulic cylinders are extending, the pull-out resistance is measured.

Data Acquisition System

The data acquisition system includes analogue to digital converters, so that the analogue signals can be immediately converted to digital forms, allowing real-time inspection of the test results.

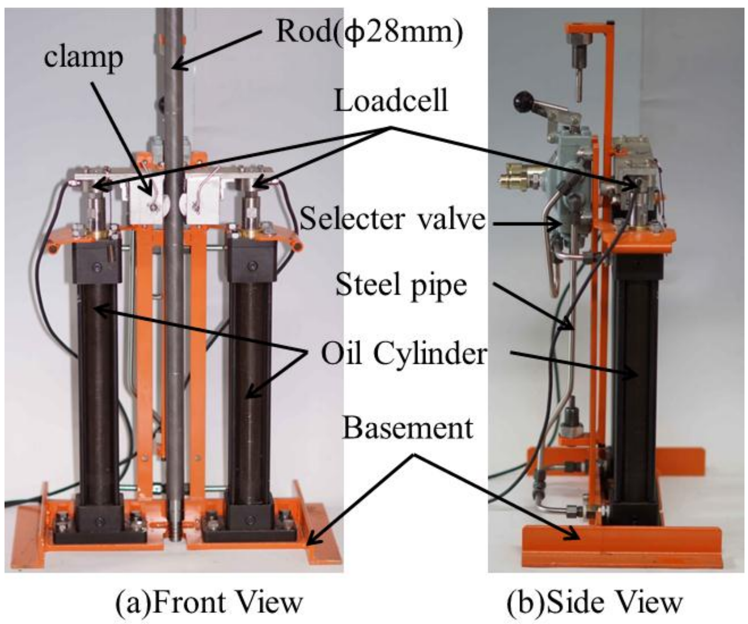


Figure 3. Newly developed pull out equipment

Data Processing

The flow chart for data processing to evaluate the liquefaction susceptibility by PPT-method is shown in Figure 4. All data except the unit weight can be obtained by PPT consisting of the dynamic penetration test and the pull-out resistance test by the quasi-static pull-out operation. The unit weight is not a sensitive quantity for evaluating the liquefaction susceptibility.

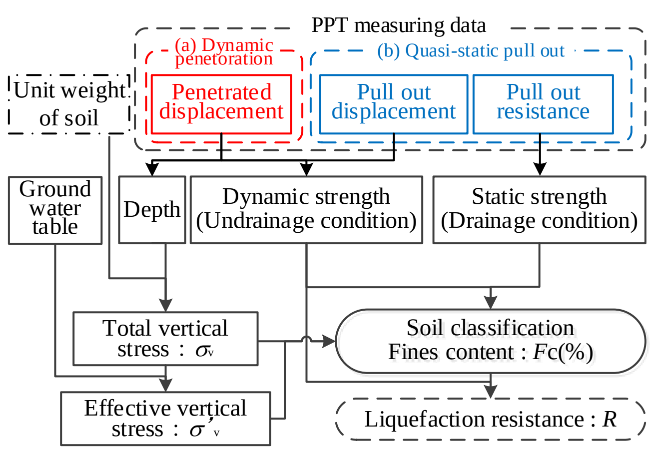


Figure 4. Flow chart of evaluating liquefaction strength using PPT

Test Site Conditions & Example Data by PPT

The test site is located in the Kanto plains area along The Tone River, Japan. The soil profile, SPT *N*-values and fine content values of soils from the laboratory test are shown in Figure 5. The surface soil layer is an unsaturated fill, which mainly consists of dredged sandy soil, interbedded with several clays of 10-50 cm in thickness. The SPT *N*-value for the fill is 4, indicating relatively loose and non-uniform soils. The fill layer exists down to 2.0 m in depth above a natural sedimentary alluvial clay layer. The groundwater level is from 0.5 to 1.0 m below the ground surface. The sandy soil is deposited from 8.2 m to 16 m in depth. The uniform sand layer consists of the medium sand with some fine contents. The *N*-value for the sandy soil is about 20, indicating medium dense and relative uniform soils.

Figure 5(c) illustrates the pull-out resistance profile of the specially-modified PPT, in which the load cell is mounted at the cone tip after the dynamic penetration. The modified PPT can take into account locally lower pull-out resistance in the sandy soil layer rather than in the clay layer during quasi-static pull-out operation.

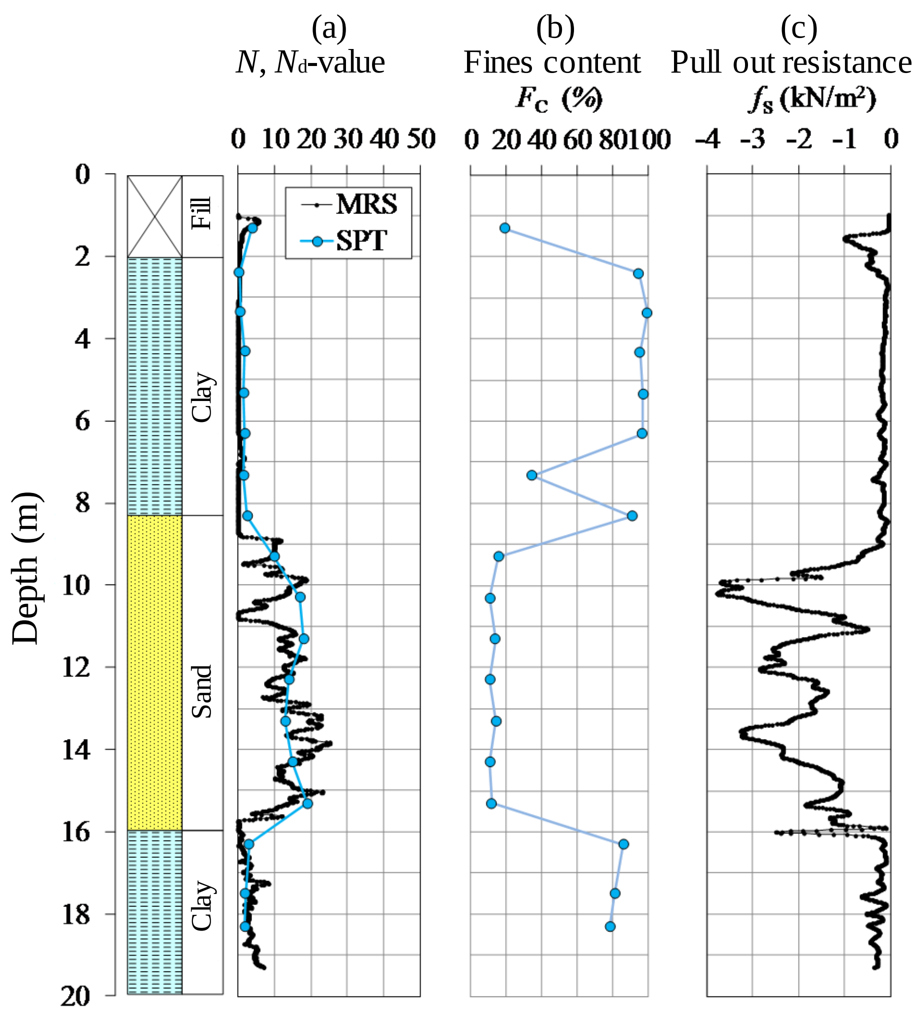


Figure 5. Soil profile by SPT and pull-out resistance

Capability of Soil Classification using PPT

Wroth (1984) suggested that CPT data should be normalized using the following parameters: Normalized penetrated cone resistance (Q_t) and normalized pull-out resistance (F_t) can be calculated from the following equation:

$$Q_t = \frac{q_t + \sigma_{v0}}{\sigma'_{v0}} \tag{2}$$

$$F_t = \frac{f_s}{q_t - \sigma_{v0}} \times 100 \tag{3}$$

where q_t = cone resistance corrected for the unequal end area effect, $q_t = 392 \times N_d$ (kN/m^2)

f_s = pull-out resistance at the cone tip (kN/m^2)
σ_{v0} = total vertical stress (kN/m^2)
σ'_{v0} = effective vertical stress, $\sigma_{v0} - u_0$ (kN/m^2)

Based on these normalized parameters and by using the extensive CPT database now available in published and unpublished sources, the modified soil behavior type classification charts have been proposed by Robertson (1990).

Figure 6 shows the example chart for soil classification between normalized penetrated cone resistance (Q_t) and normalized pull-out resistance (F_t) based on PPT data.

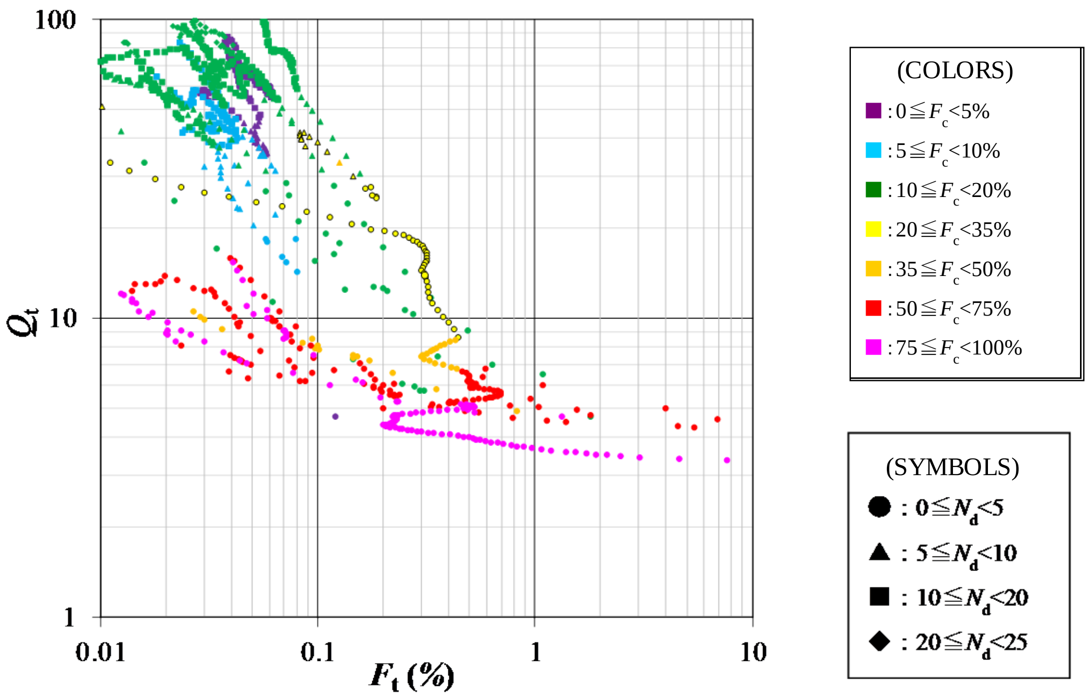


Figure 6. Example for soil classification chart based on PPT

Colors of the legend show the range of fine contents. The warm colors, for instance, from orange to red color indicate the high fine contents that is clayey soil, and cool colors, for instance, from yellow to blue color indicate the low fine contents that is sandy soil. The distribution of the relationship between normalized penetratation cone resistance (Q_t) and normalized pull-out resistance (F_t) based on PPT data shows that these data can be used for the soil classification.

Correction of Pull-out Resistance

The pull-out resistance data in Figure 6 have been obtained using the load cell at the tip of cone. The goal of this study will be achieved by measuring the pull-out resistance using the load cell at the pull-out equipment on the ground during the pull-out operation without an electrical cable pre-threaded down the hollow sounding rods.

In order to convert the pull-out resistance from the data on the ground surface to tip of cone, a modified system including two load cells, one located in the tip of cone and the other at the of the pull-out equipment on the ground surface, has been developed. An example of the converted pull-out resistance at the tip of cone is illustrated in Figure 7.

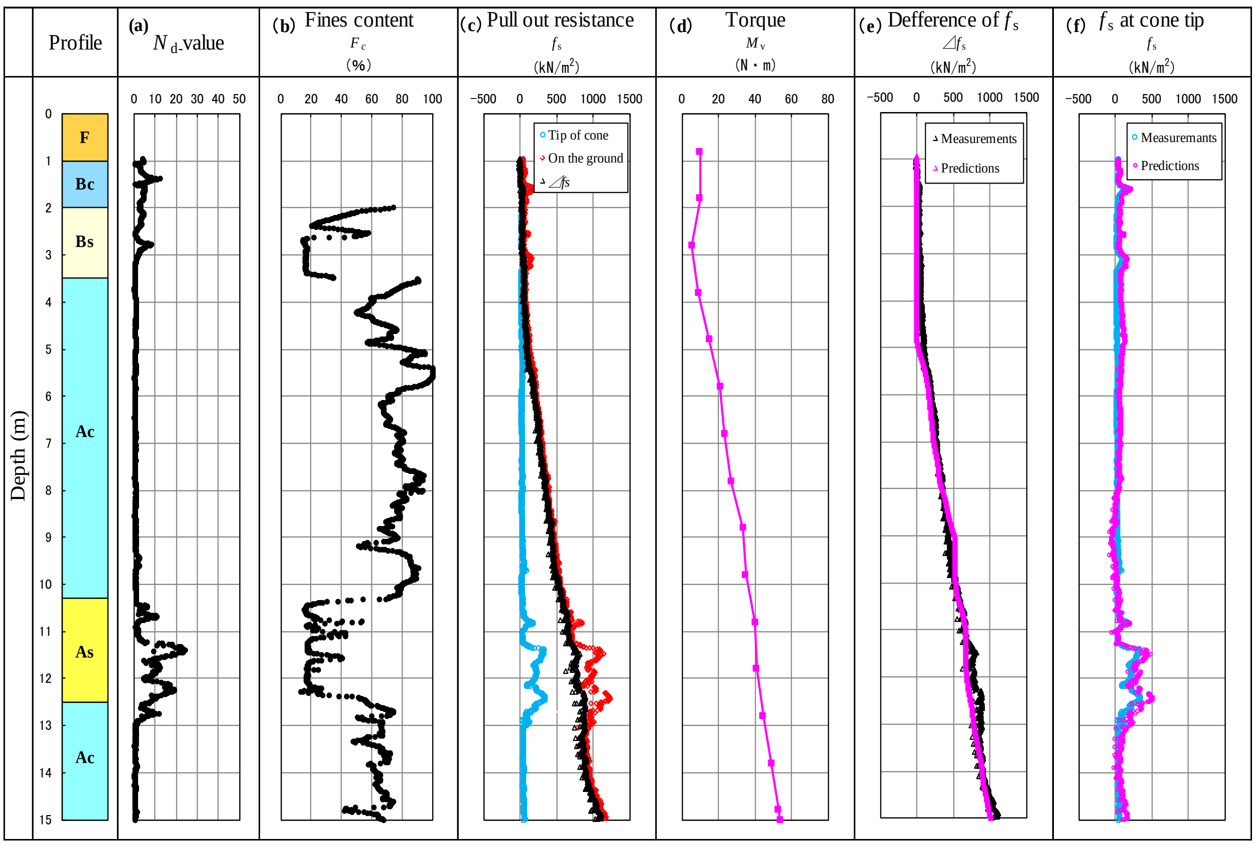


Figure 7. Example of Soil profile and results of PPT

The test site is located, as the same as at Figure 5, in the Kanto plains area along The Tone River, Japan. The soil profile, N_d-values using PPT and fine content of soils using PDC, pull-out resistance, measured torque during the dynamic penetration, difference of resistance between the anvil and the apex and converted resistance at the cone apex are shown in Figure 7. In order to obtain the point resistance with reasonable accuracy, side friction resistance was determined by measuring torques. The method measures the torque required to rotate the rods at the ground surface with torque wrench per 1meter of penetration, applied to the sounding rods. The fill layer exists down to 3.5 m in depth above a natural sedimentary alluvial clay layer. The groundwater level is 2.0 m below the ground surface. The sandy soil is deposited from 10.3 m to 12.4 m in depth. The uniformed sand layer consists of medium sand with about 20% of fine contents.

Figure 7(e) shows the distribution of measured pull-out resistance with depth using the load cell which is located at the tip of cone. And these predicted differences of the pull-out resistance using two load cells which are located at pull-out equipment on the ground surface and the tip of cone are plotted in the figure. The predicted pull-out resistance which is converted using measured torque can be calculated from the following equation:

$$\Delta f_s = 26 \times M_v - 390 \quad (4)$$

where Δf_s = difference of pull-out resistance between the tip of cone and the ground
M_v= measured torque during the dynamic penetration

The predicted difference of the pull-out resistance in this case is good agreement with the measurement.

The reason why the proposed method using measured torque during the dynamic penetration by PPT has good agreement is that this issue is concerned with the rod friction. The measured torques just indicate the difference of the pull-out resistance between the tip of cone and the ground surface.

Conclusions

The following conclusions were obtained from a series of dynamic penetration and quasi-static pull-out resistance test results.

(a) The distributions of the converted N_d-values by a single blow can be used to identify the uniformity of layer and to find inter-bedded layers.

(b) The distributions of the relationship between normalized penetrate cone penetration resistance (Q_t) and normalized pull out resistance (F_t) based on PPT data shows that these data can be used for the soil classification.

(c) The difference of pull-out resistance between the tip of cone and the ground surface during quasi-static pull-out operation is significantly affected by the measured torques. This issue is not concerned with complicated soil type as mentioned above.

(d) Information concerning the dynamic penetration and the combination quasi-static pull out resistance on the ground surface and measured torque can be used as essential correction factors for determining the soil classification and the liquefaction susceptibility.

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