Mem. Fac. Sci. Eng. Shimane Univ.
Series A
37, pp. 1-6 (2003)

The interpretation of the flat dilatometer tests in Ariake clay, southwest Japan

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Abstract

The flat dilatometer in-situ testing device (DMT) provides an extremely rapid, repetitive, reliable and economic means of determing geotechnical properties from one sounding. It also has significant advantages in that the equipment is relatively simple, rugged and the procedure is easy to carry out. To investigate the usefulness of the DMT, one field application was carried out on Saga Plain (Ariake site). Results from DMT give reasonably accurate predictions of soil classification, undrained shear strength (c_u), deformation modulus (E_{50}), and overconsolidation ratio (OCR). We conclude, therefore, that DMT has an important role to play as a profiling tool to provide useful information for in-situ soil parameter predictions. To this end, we reconfirm that the DMT is easy to use, is cost effective, and is a versatile in-situ test which produces results comparable to other tests.

1. Introduction

The flat dilatometer in-situ testing device (DMT)[1)] has been used frequently in North America and Europe during the brief period since its introduction. The DMT has several significant advantages: (i) the equipment is relatively simple and rugged, (ii) the procedure is easy to carry out and can be used repetitively and rapidly, (iii) tests can be carried out for most soil types, and (iv) many useful correlations have been developed. The procedure consists of a potential in-situ penetration plus dilation (expansion) test[2)].

The DMT test consists of forcing the steel dilatometer blade vertically into the soil to a desired test depth, measuring the thrust to accomplish this penetration, and then using gas pressure to expand a circular steel membrane located on one side of the blade. Figure 1 shows a schematic diagram of DMT system. More detailed schematic diagrams of DMT system have also been described elsewhere [1)-3)].

The flat dilatometer is a flat plate 16mm thick, 93mm wide by 232mm in length. A flexible stainless steel membrane 60mm in diameter is located on one face of the blade. Beneath the membrane is a measuring device which turns a buzzer off un the control box at the surface when the membrane starts to lift off the sensing disc, and turns a buzzer on again after a deflection of 1mm at the center of the membrane has occurred. At 20cm intervals the penetration thrust is recorded, and three pressure readings are obtained by pneumatically expanding the diaphragm. Readings are made from a pressure gauge in the control box. The DMT were pushed into the ground at a constant rate of penetration of 2cm/sec. The test provides information about the soil's in-situ stratigraphy, stress, strength, compressibility, and pore

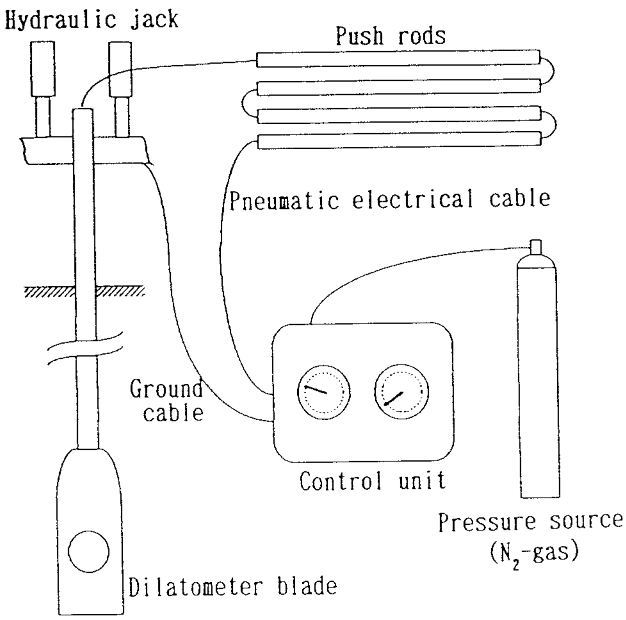

Figure 1 Schematic diagram of Flat Dilatometer (DMT)

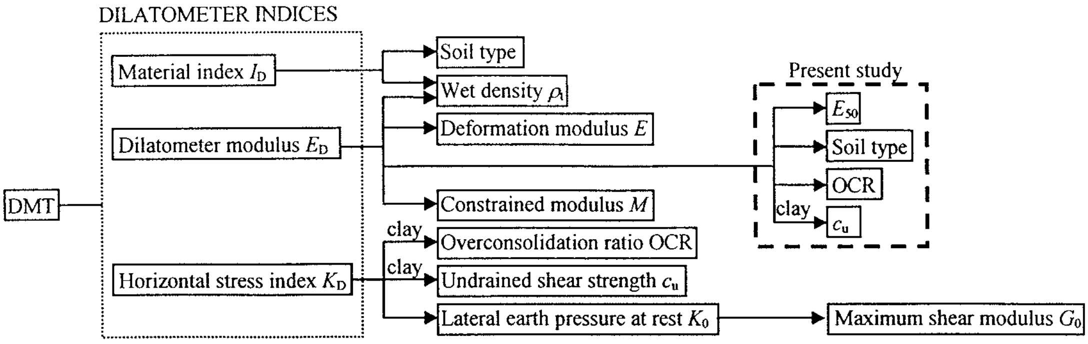

Figure 2 Flat Dilatometer (DMT) data deduction flow

pressure for use in the design of earth works and foundations[2),3)].

The DMT test results are interpreted using the material index, I_D, K_D, E_D, as defined by Marchetti[1)]. The I_D-value is used to determine soil type. K_D–value is related to the in-situ coefficient of earth pressure at rest, and is also used to derive the overconsolidation ratio and the undrained shear strength. E_D-value characterizes the stress-displacement curve during the 1mm expansion, and is related to the stiffness of the soil. The total time needed for obtaining a 15m profile is about 1 hour, if no obstructions are encountered.

The original correlations proposed by Marchetti[1)] , however, were based on a limited amount of data. At this stage, to investigate the usefulness of Marchetti's equations regarding several soil parameters, DMT was carried out at several sites in Japan[2),4)-7)]. As a result, results from DMT gave reasonably accurate predictions of soil parameters in geotechnical engineering design except for undrained shear strength of cohesive soils. At this stage, they developed new equations of undrained shear strength and overconsolidation ratio of cohesive soils appropriate for general use in Japan[8)].

The purpose of this paper is to reconfirm the usefulness of the flat dilatometer in-situ testing device (DMT) on Saga Plain (Ariake site), a lowland in north of the Ariake Sea in Kyushu, Japan. We focused on the evaluation of soil type, undrained shear strength, and overconsolidation ratio of cohesive soils as shown in Figure 2.

2. Prediction of undrained shear strength and overconsolidation ratio of cohesive soils using a flat dilatometer

Marchetti[1)] suggested estimating the undrained shear strength c_u as a function of the K_D-value. The dependence of c_u/σ_{vc}' on OCR is well recognized. The indication of a relationship between K_D and OCR prompted an investigation on the correlation c_u/σ_{vc}' versus K_D. The undrained shear strength can be expressed as[1),9)]

$$(c_u/\sigma_{vc}')_{oc}=(c_u/\sigma_{vc}')_{nc}(0.5K_D)^{1.25} \quad ...(1)$$

Equation (1) can be rearranged as follows.

$$c_u=(c_u/\sigma_{vc}')_{nc}\,\sigma_{vc}'(0.5K_D)^{1.25}$$
$$=0.22\,\sigma_{vc}'(0.5K_D)^{1.25} \quad ....(2)$$

As seen in Equation (2), Marchetti[1)] assigned to $(c_u/\sigma_{vc}')_{nc}$=0.22 obtained from field vane tests as suggested by Mesri[10)].

In most cases in Japan, however, c_u is determined from the unconfined compression test[11)]. Regarding this, Kamei and Iwasaki[8)] recommended, that the $(c_u/\sigma_{vc}')_{nc}$=0.35, if the Japanese design manual is to be used[12)]. They also showed the relationship between K_D and OCR based on previously published data and their Japanese data. By combining Equation OCR=$(0.47K_D)^{1.43}$ and $(c_u/\sigma_{vc}')_{nc}$ =0.35, Equation (2) can be rearranged as follows.

$$c_u=(c_u/\sigma_{vc}')_{nc}\,\sigma_{vc}'(0.47K_D)^{1.14}$$
$$=0.35\,\sigma_{vc}'(0.47K_D)^{1.14} \quad ....(3)$$

Undrained shear strength obtained from unconfined compression tests and that from Equations (2) and (3) proposed by Marchetti[1)] and Kamei and Iwasaki[8)] respectively were compared[2),4)-7)]. Reasonable agreements have been obtained between observed and calculated results for undrained shear strength determined by Kamei and Iwasaki[8)].

To reconfirm the applicability of the equations proposed by Marchetti[1)] and Kamei and Iwasaki[8)] to other localities, DMT was carried out at site in the Saga plain(Ariake site).

3.Geologial features and index properties at the Ariake site

Saga Plain, a lowland less than 5m above mean sea level, and has an area of about 400km^2. It lies in north of the Ariake Sea in Kyushu, Japan. Thick under-consolidated sediments underlie the plain. Saga Plain in surrounded by Seburi

Mountain (Mesozoic granite and Sangun metamorphic rocks and serpentinite) in the north, the Minou and Chikushi Mountains (Sangun metamorphic rocks) to the east, the Oninhanayama, Kishimayama and Taradake Mountains (Paleocene sediments and Neogene to diluvial volcanic rocks) in the west, and the Ariake Sea to the south. The

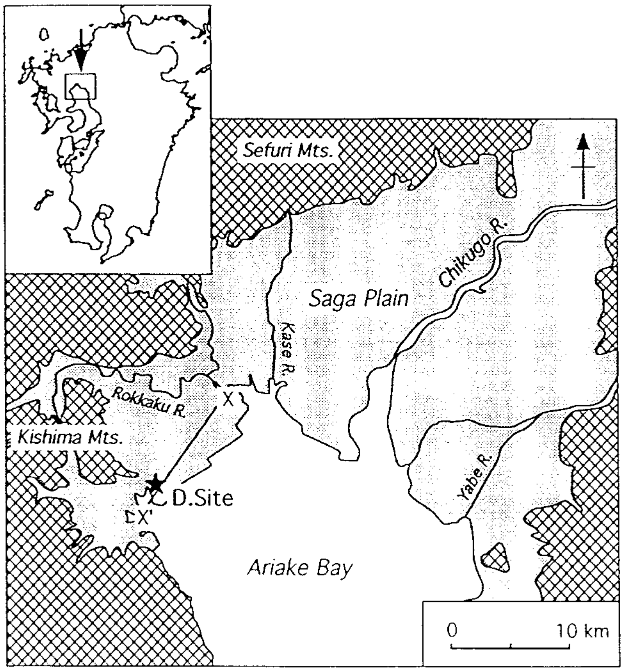

Figure 3 Site location of the present study

Chikugo, Kase and Rokkoku are the main rivers that flow through the Saga Plain. All enter the Ariake Sea. The Kase River flows from the granite area and thus carries a large amount of sand. In some places, the bed of the river is higher than the surrounding floodplain[13].

The location of the site in the present study is shown in Figure 3, and variations of grain size and water content with depth are shown in Figures 4 (a) and (b), respectively. The soil stratum consists of a Holocene clay deposit. Liquid limit w_L and plastic limit w_p are relatively high for usual Japanese marine clay, and the natural water content w_n exceeds w_L. This suggests that the in-situ stress state of the clay to the depth of 14m is evaluated as under-consolidated. In addition, the natural water content w_n equals w_L at the depth of 15 to 17.5m. This means that the in-situ stress state of the clay is evaluated as normally consolidated.

4. Test results and discussions

Dilatometer indices, I_D, K_D, and E_D derived from DMT data to a depth of 17.5m at the site are shown in Figure 5. Figure 6 shows the variation of I_D-value with depth. No noticeable I_D variation is observed in the main formation. As mentioned earlier, the I_D-value can be used to identify soil type using the classification system. The results in the figure for soil type shows reasonably good agreement between the predicted and the results for particle size distribution of soils with only one soil samples classified as silt. In the clay layer the K_D-value is almost constant ($K_D \fallingdotseq 2.0$), and the E_D-value

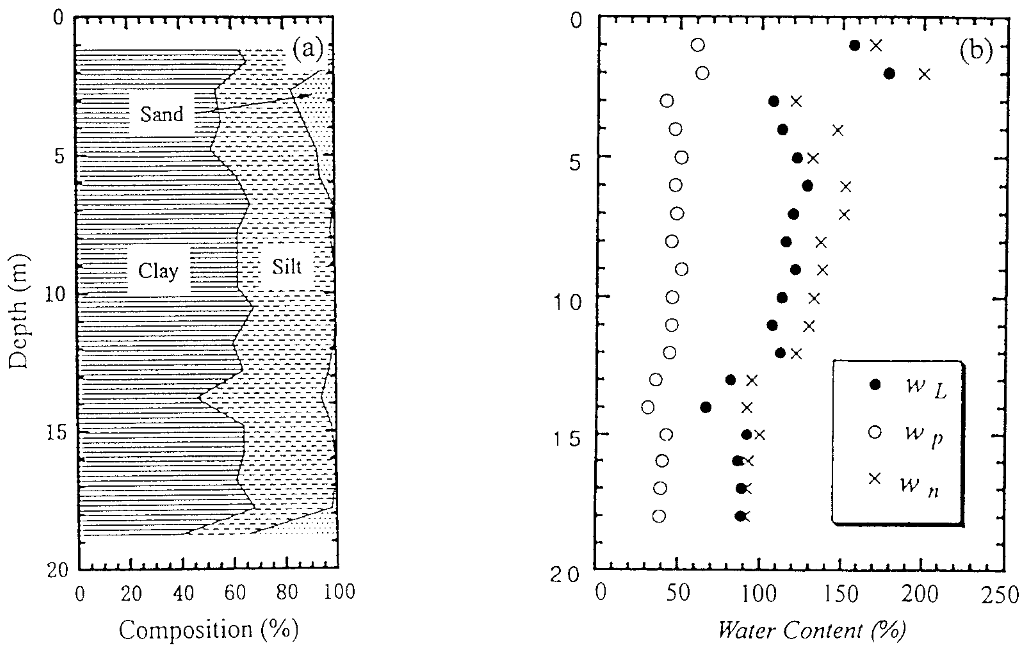

Figure 4 Grain size distribution and water content with depth

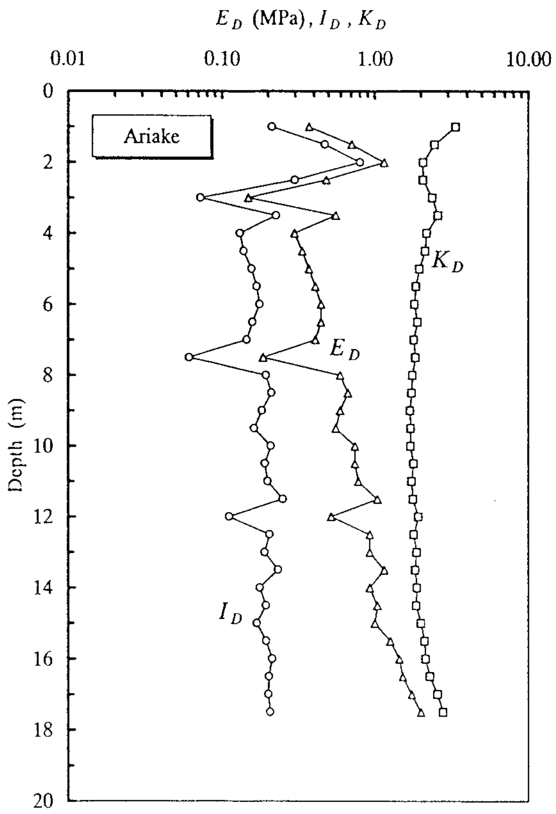

Figure 5 DMT derived data for intermediate parameters, I_D, K_D, and E_D to a depth of 17.5m at the Ariake site

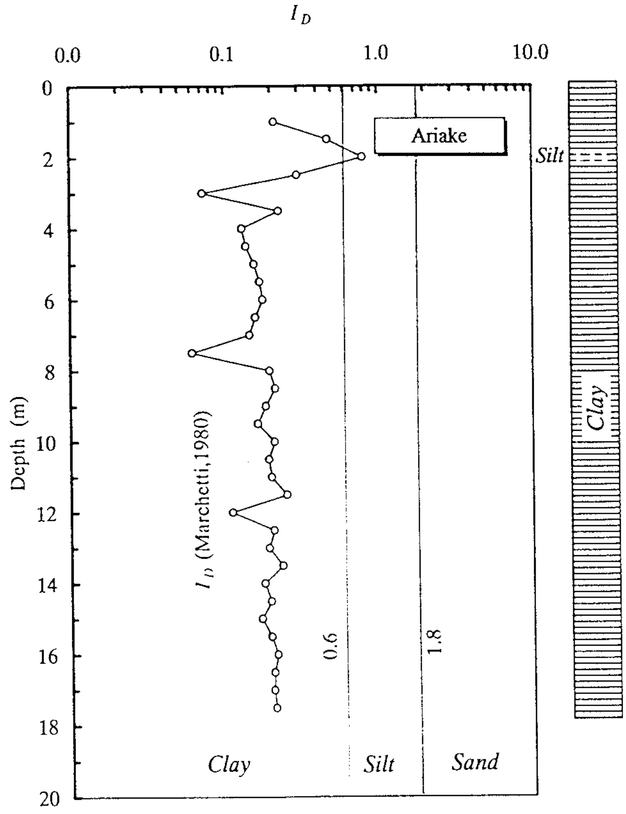

Figure 6 Variation of I_D-value with depth and its interpretation of soil type

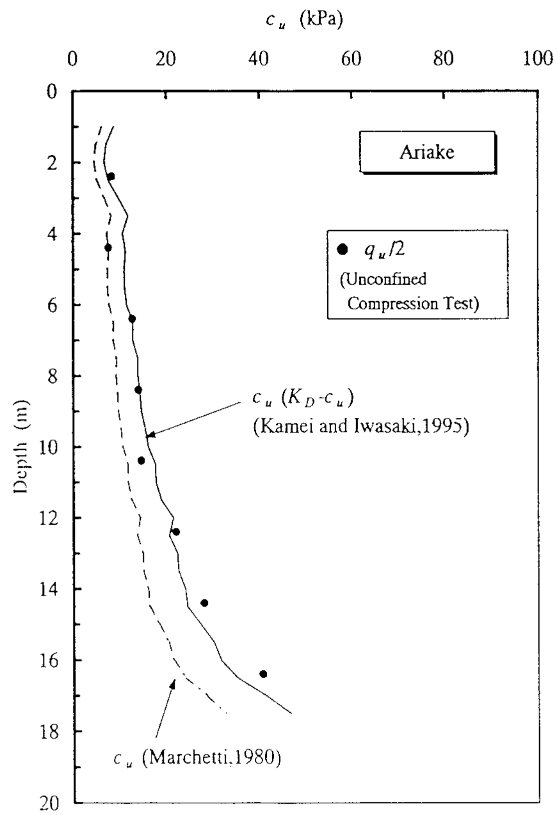

Figure 7 Comparison of undrained shear strength profiles interpreted from DMT and unconfined compressive strength

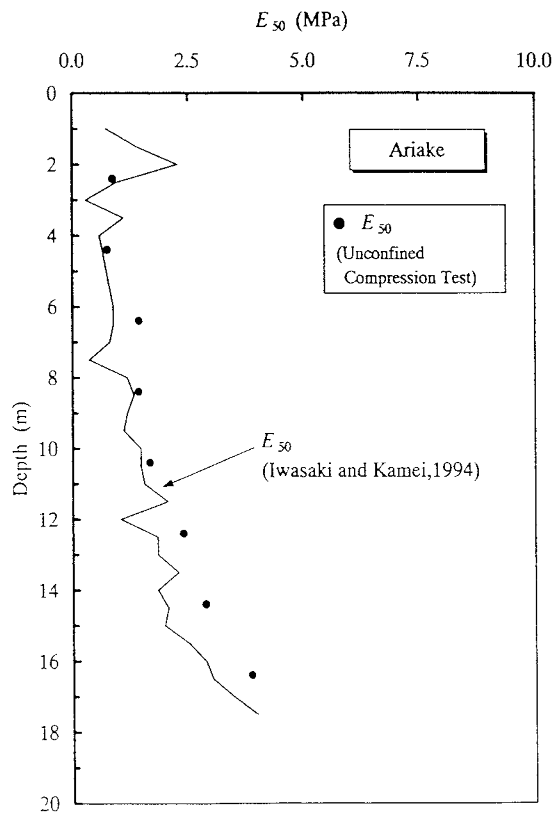

Figure 8 Variation of deformation modulus with depth

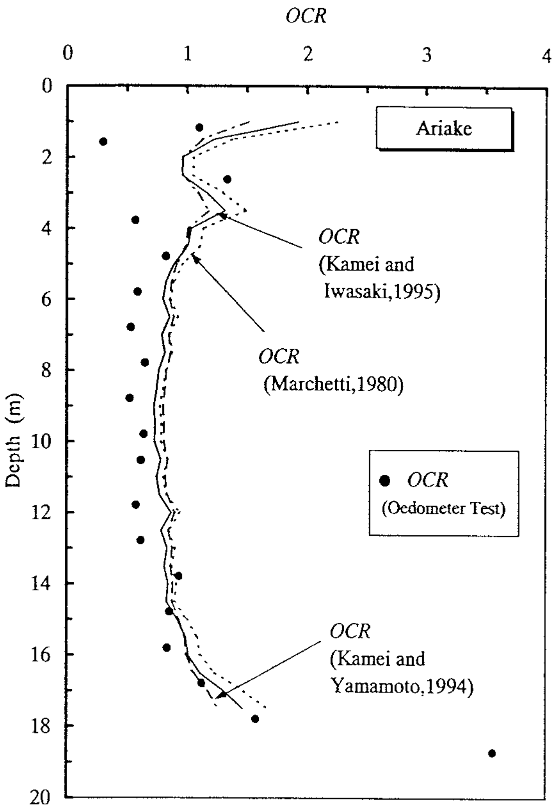

Figure 9 OCR profile interpreted from DMT using KAMEI and Iwasaki[8], Kamei and Yamamoto[4], and Marchetti's[1] correlations

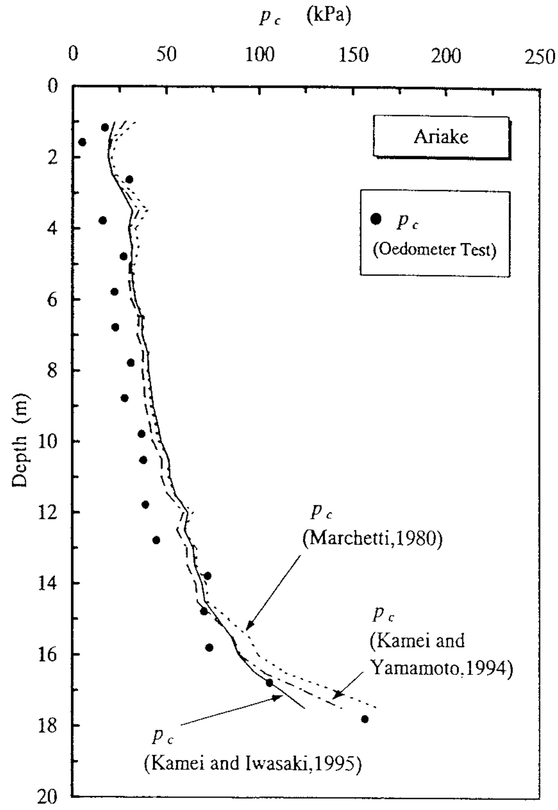

Figure 10 Pre-consolidation stress (p_c) profile interpreted from DMT using KAMEI and Iwasaki[8], Kamei and Yamamoto[4], and Marchetti's[1] correlations

increase approximately linearly with depth, as seen in Figure 5.

Figure 7 shows the comparison of the undrained shear strength profiles interpreted from Marchetti's and Kamei and Iwasaki's equations based on K_D-value and the laboratory-measured c_u based on unconfined compressive strength. When the interpreted values are compared with the unconfined compression test results, the K_D method proposed by Marchetti[1] appears to provide conservative estimates, however, the K_D method proposed by Kamei and Iwasaki[8] gives reasonable estimates of c_u for the Ariake site. The reasons for the underestimate of undrained shear strength c_u using Marchetti's equation for cohesive soils include the assumption of the value of $(c_u/\sigma_{vc}')_{nc}$ obtained from different testing conditions (vane shear test). The calculated results obtained using the new equation is found to be reasonable, and therefore the use of this equation in geotechnical engineering practice in Japan is encouraged. Comparison has also been made between the observed and the predicted deformation modulus E_{50} proposed by Iwasaki and Kamei[5], as shown in Figure 8. Reasonable agreement was obtained between the observed and the predicted E_{50} for the soil layers. Figures 9 and 10 show the OCR and pre-consolidation stress (p_c) profiles for Ariake site interpreted from DMT using Kamei and Iwasaki[8], Kamei and Yamamoto[4] and Marchetti's[1] correlations. The OCR and p_c values interpreted from the DMT on the basis of the three equations show slightly high when compared with the oedometer values. These equations, however, give a reasonably accurate prediction of overconsolidation ratio in the engineering sight of view. As a result, we reconfirm that the DMT offers a promising means of obtaining a volume of data because of the ability of the DMT to obtain economic, repeatable, and near continuous data of soil response.

5. Conclusions

An attempt was made to investigate the usefulness of the flat dilatometer on Saga Plain (Ariake site), southwest, Japan. This shows that using DMT to determine soil classification, undrained shear strength (c_u), deformation modulus (E_{50}), and overconsolidation ratio (OCR) gives very encouraging results. We conclude, therefore, that DMT has an important role to play as a profiling tool to provide useful information for in-situ soil parameter predictions. Finally, we reconfirm that the DMT is easy to use, is relatively rugged, is cost effective, and is a versatile in-situ test which produces results comparable to other tests.

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Appendix

*: in Japanese with English abstract