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SUMMARY The paper presents the results of measurement on the dynamic modulus of deformation and damping ratio of dense sand or stiff clay of the Pleistocene epoch using a dynamic pressuremeter. The paper first describes an outline of an instrument and procedures of the dynamic pressuremeter test, which include necessary correction of data for eliminating the influence of compressibility and damping of the instrument. From the results of field measurement, the moduli derived from the dynamic pressuremeter tests were found several times greater than those from laboratory tests which were affected by disturbance of soil samples.

INTRODUCTION

The dynamic shear modulus has been determined from empirical correlation with the velocity of shear wave or blow count of the standard penetration test. More sophisticated approach has been made by dynamic triaxial tests. However, it is known that the modulus obtained from laboratory tests is affected by disturbance of samples. The attempt to measure dynamic modulus in situ has recently been developed in Japan (Mori et al., 1975)(Esashi et al., 1977). The paper presents the results of dynamic pressuremeter tests in dense sand or stiff clay of the Pleistocene epoch. It was found from this study that the dynamic pressuremeter test could obtain better results than triaxial tests whose results were seriously affected by sample disturbance of the Pleistocene soils.

INSTRUMENT AND PROCEDURE OF DYNAMIC PRESSUREMETER TEST

The mechanism of dynamic pressuremeter is schematically illustrated in Fig. 1. The pressuremeter probe consists of a perforated metal cylinder covered with a cylindrical membrane at the lower end of an instrument shown in Fig. 1.

Dynamic pressure is applied, after the probe is inflated by static pressure, by a cyclic motion of the hydraulic piston(2) driven by the hydraulic motor(3) and regulated by the servo-valve controller(4). The pressure and volume change of the probe are picked up by the pressure sensor(6) and differential transformer(5), respectively. Further details of the instrument and procedure of the dynamic pressuremeter test are presented in the paper of the first author (Mori, 1979).

The equivalent shear modulus and the equivalent damping ratio are given by the following equations :

$$G_{eq} = (V_o + V_m)\ \frac{p}{v} \qquad (1)$$

$$h_{eq} = \frac{1}{2}\ \tan(\sin^{-1} \frac{\delta V}{v}) \qquad (2)$$

(Yamamoto and Hayashi, 1973)

where V_o : volume of pressuremeter probe before inflated
V_m : volume of water statically injected into the probe
G_{eq} : equivalent shear modulus
h_{eq} : equivalent damping ratio
p : dynamic pressure, $p = p_o e^{i\omega t}$
v : volume change corresponding to pressure p
δV : width of hysteresis curve (See Fig. 2)

The hysteresis curve obtained from 10th cycle of cyclic motion in dynamic pressuremeter tests is shown in Fig. 2. The equivalent shear modulus and damping ratio can be calculated knowing parameters p,v, and δV from the hysteresis curve. The volume change, v, obtained from the pressuremeter test includes volumetric compression of rubber membrane. The damping ratio calculated by equation (2) includes energy absorbed by the instrument. Therefore, the modulus and damping of ground have to be determined after correcting parameters for compressibility and damping of the probe.

Assuming a model consisting of two pairs of a spring and a dashpot as illustrated in Fig. 3, the volume change of the probe, v, is given by the equation :

$$v = v_s + v_m \qquad (3)$$

$$v_s = (K_s + i\omega C_s)p \qquad (4)$$

$$v_m = (K_m + i\omega C_m)p \qquad (5)$$

where v_s : volume change equivalent to the displacement of a borehole
v_m : volume change due to compressibility of the probe
v : measured volume change

K_s, C_s and K_m, C_m : constants of linearlity between pressure and volume change
p : dynamic pressure; $p = p_o e^{i\omega t}$

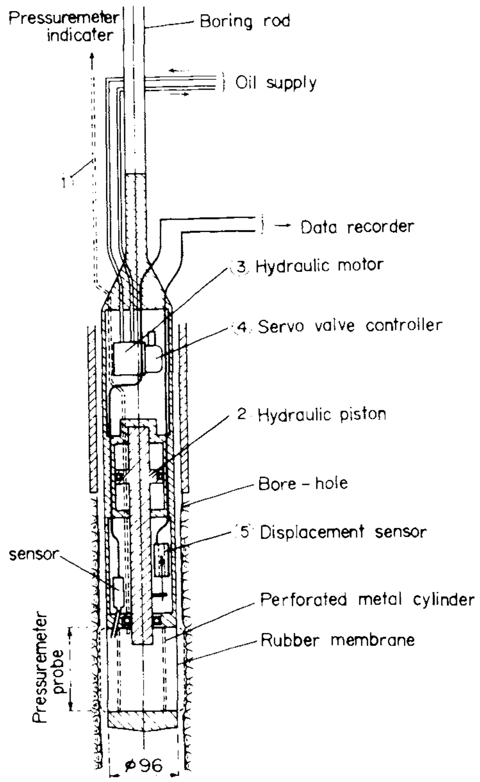


Fig.1 Schematic Diagram of Dynamic Pressuremeter

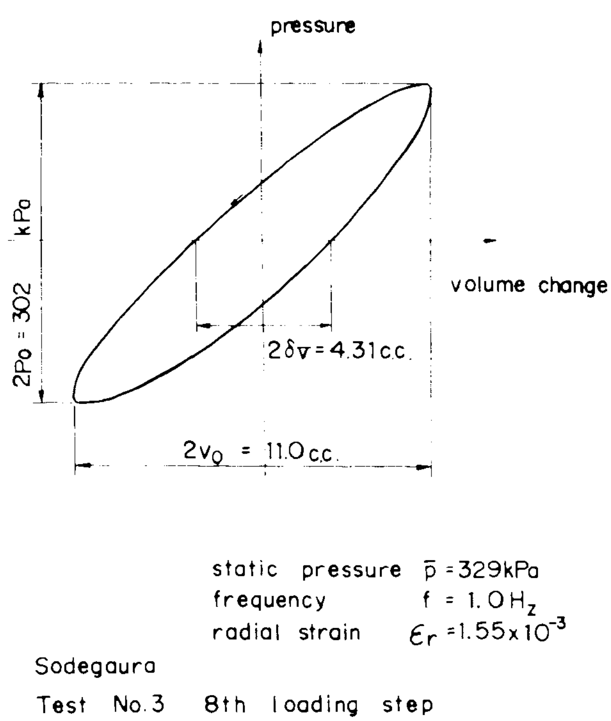


Fig. 2 Hysteresis curve obtained from dynamic pressuremeter test

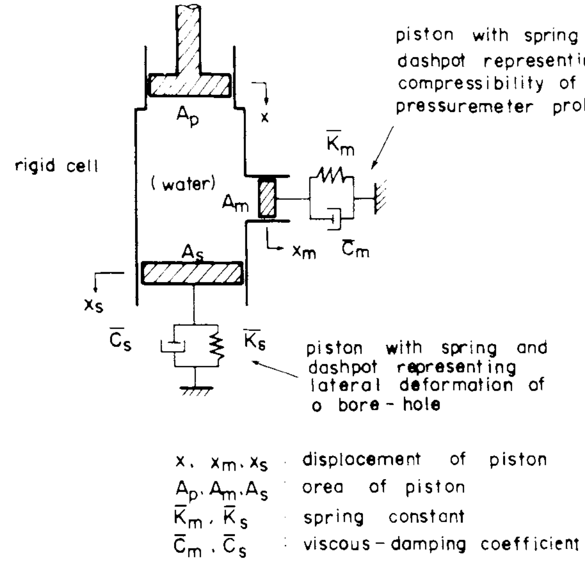


Fig. 3 Mathematical model of dynamic pressuremeter test

For the pressuremeter probe inflated inside of a rigid steel pipe, v_s being assumed zero,

$$v = v_m = (K_m + i\omega C_m) p_o \cdot e^{i\omega t} \tag{6}$$

Substituting $v = v_o \cdot e^{i(\omega t+\phi)}$ into equation (6)

$$v_o e^{i(\omega t+\phi)} = (K_m + i\omega C_m) p_o e^{i\omega t}$$

$$e^{i\phi} = \frac{p_o}{v_o}(K_m + i\omega C_m)$$

$$\therefore \begin{cases} K_m = \dfrac{v_o}{p_o}\cos\phi & (7) \\ \omega C_m = \dfrac{v_o}{p_o}\sin\phi & (8) \end{cases}$$

From a hysteresis curve obtained from the dynamic pressuremeter test using a probe placed inside a rigid pipe, the angle ϕ can be calculated from the equation : $\phi = \sin^{-1}(\frac{\delta v}{v_o})$, then the coefficients K_m and C_m are obtained from equation (7) and (8). Using those coefficients, the corrected coefficients of ground may be obtained by the following equation :

$$K_s = \frac{v_o}{p_o}\cos\phi - K_m \tag{9}$$

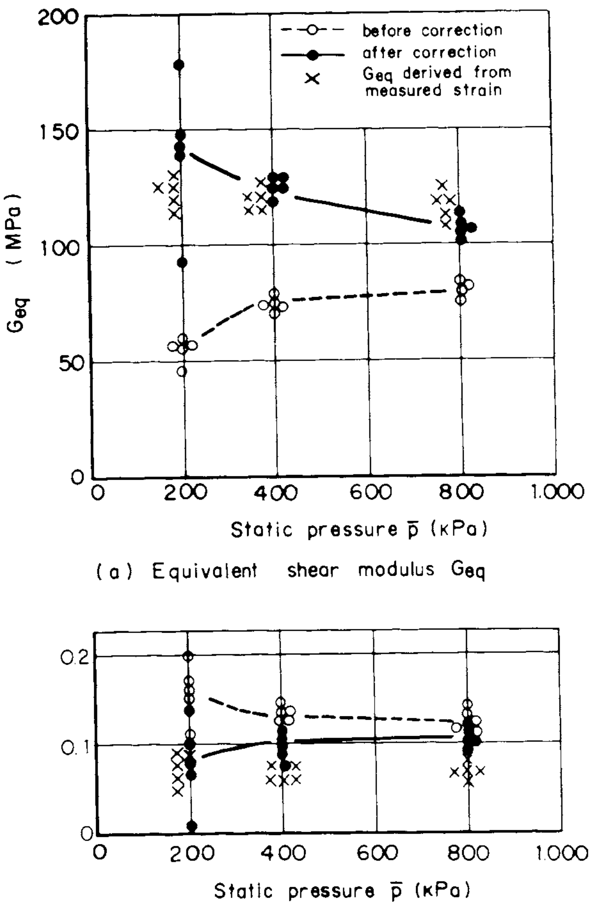
$$\omega C_s = \frac{v_o}{p_o}\sin\phi - \omega C_m \tag{10}$$

The equivalent shear modulus and damping ratio may be represented as functions of the coefficients, K_s and C_s, in eq. (9) and (10) [See eq. (1) and eq. (2)].

$$G_{eq} = \frac{(V_o + V_m)}{K_s} \tag{11}$$

$$h_{eq} = \frac{1}{2}\tan\phi = \frac{\omega C_s}{2K_s} \tag{12}$$

The coefficients K_m and C_m of equation (7) and (8) were obtained from dynamic pressuremeter tests using a probe placed inside a steel pipe of 5 to 6 mm thick, and having diameters 96, 99, 102 and 105 mm. Then the coefficients K_s and C_s of equation (9) and (10) were calculated from the results of dynamic pressuremeter tests using a probe placed inside of a flexible pipe made of vinyl chloride of 102 mm in diameter and 3 mm thick. Applying the coefficients K_s and C_s to equation (11) and (12), the equivalent shear modulus and damping ratio for the flexible pipe were obtained. The results of dynamic pressuremeter tests in a flexible pipe are illustrated in Fig. 4.



(b) Equivalent damping ratio h_{eq}

Fig. 4 Equivalent dynamic shear modulus and damping ratio of a flexible pipe before and after correction

The circumferential strain on the surface of the flexible pipe was measured by four strain gauges installed at an equal interval. The equivalent modulus and damping of the flexible pipe derived directly from the strain of the flexible pipe are plotted in Fig. 4 in comparison with the parameters obtained from pressuremeter tests. The parameters obtained from the dynamic pressuremeter test and corrected for compressibility and damping of the probe are well correlated to those calculated from the measured strain of the flexible pipe.

FIELD MEASUREMENT OF PLEISTOCENE SOILS

The test site was selected at Sodegaura in the East coast of Tokyo Bay. The site was covered with alluvium and fill to the depth of 12 m, below which was underlain with alternating layers of the Pleistocene sand and cohesive soils. The dynamic pressuremeter test was carried out at three depths in the Pleistocene deposits, i.e. 14.30, 17.00 and 18.00 m below the ground surface. Two additional tests were made in alluvium at the depths 7.00 and 9.50 m. Index properties of soil at the test site are summarized in Table I.

Table I Index Properties of Soil at the Site of Sodegaura

depth(m)	soil type	water content(%)	void ratio	fine content(%)
1 - 4.8	sand fill			
4.8- 7.5	loose fine sand with a thin layer of silt	38	1.0	17
7.5-12.0	alluvial clayey silt	50	1.3	95
12.0-14.5	alternating layers of sand and clay	35	1.1	85
14.5-20.0	fine sand	30	0.9	10

One of the results obtained from the dynamic pressuremeter test in the Pleistocene soils is illustrated in Fig. 5 (a) and (b). In Fig. 5 (a) is shown the shear modulus plotted against strain. The shear modulus obtained from dynamic pressuremeter tests was plotted after it was corrected for compressibility and damping of the probe. The shear modulus derived from the dynamic pressuremeter test was several times greater than that obtained from the dynamic triaxial test.

The dynamic pressuremeter test could not be free from soil disturbance caused by boring, but the extent of disturbance around a borehole was possibly less than disturbance of samples taken by a triple tube sampler. The static modulus measured by a self-boring pressuremeter devised by the first author (Mori, 1980) and Menard pressuremeter are also plotted in Fig. 5 (a) as reference. The equivalent damping ratio obtained from dynamic pressuremeter tests was considerably higher than that obtained from triaxial tests as shown in Fig. 5 (b).

The results of dynamic pressuremeter tests at different depths are summarizingly illustrated in Fig. 6. In this figure the range of strain in which the shear modulus was obtained was shown by figures in brackets. The shear moduli obtained from the velocity of shear wave measured by the down hole method was also plotted against depth as shown in Fig. 6. The static modulus obtained from pressuremeter test was also plotted.

CONCLUSION

The shear modulus and damping ratio of the Pleistocene soils obtained from dynamic pressuremeter tests and corrected for compressibility and damping of the instrument is greater than the modulus obtained from triaxial tests, and it appears closer to the modulus in situ. The modulus obtained by a self-boring pressuremeter is higher than that from Menard pressuremeter, but it is 20 to 50 times lower than that obtained from dynamic pressuremeter tests.

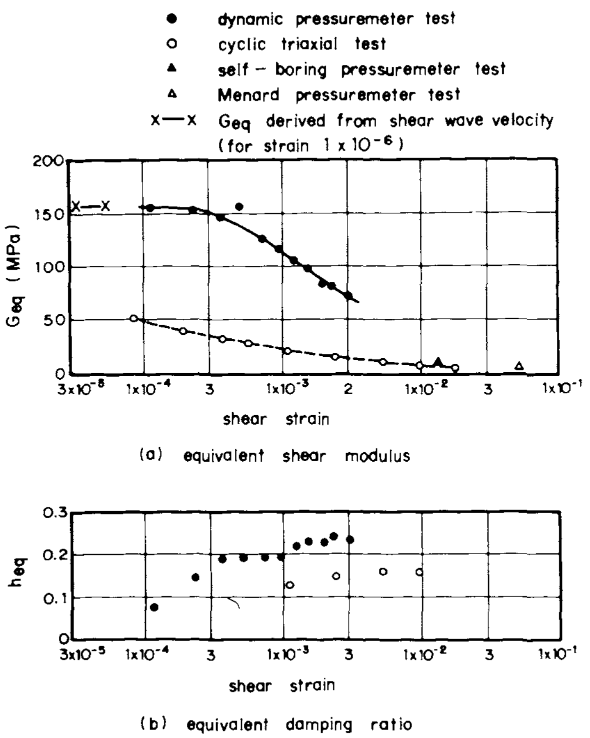


Fig. 5 Equivalent shear modulus and damping ratio obtained from dynamic pressuremeter test compared to cyclic triaxial test (test No.3, Sodegaura)

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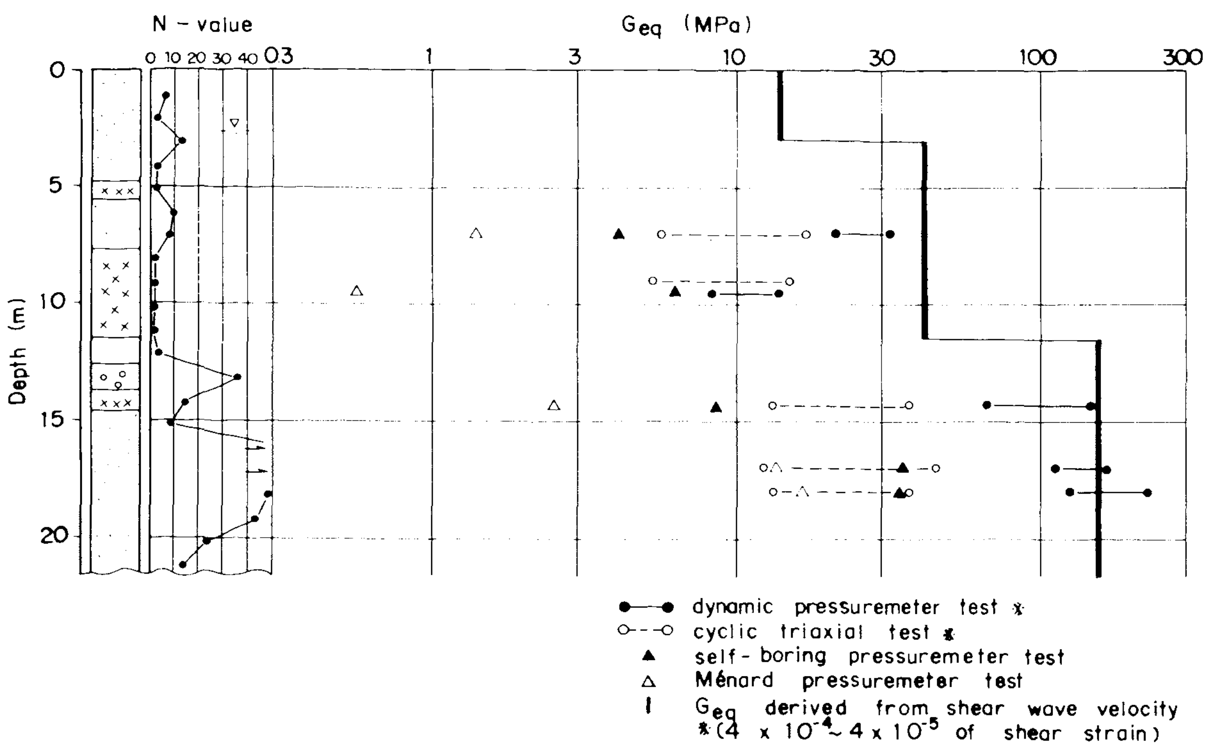

Fig. 6 Dynamic and static modulus at different depths of ground, Sodegaura