

Preface

The present paper is a shortened English version of our Japanese reports ^{1,2)} issued soon after the large scale field tests on the ultimate bearing capacity and the settlement characteristic of sand gravel layers, carried out in Kobe in 1965.

A copy of this paper is to be submitted to the 3rd Asian Regional Conference on Soil Mechanics and Foundation Engineering held at Haifa in Israel this autumn.

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Foundation Section

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Abstract

For the preliminary survey of proposed long suspension bridges between Honshuh (Japan's main island) and Shikoku, a series of load tests on various circular rigid plates (37.5, 75, 150 and 300 cm in diameter) were carried out for the purpose of investigating the ultimate bearing capacity and the settlement characteristic of the diluvial sand-gravel layers distributed around the Akashi Straight. In carrying out the tests the authors were especially interested in studying the effect of the plate size upon the settlement of the ground, in order to estimate the amount of settlement and to evaluate the coefficient of soil reaction of the prototype bridge foundations.

The maximum load applied was 2,000 tons for the largest plate with settlement of 5.9 cm. As the result of the tests, the relationship among the plate size, the amount of the settlement and apparent modulus of deformation of the ground was clarified to some extent.

In this paper only the settlement characteristic of the sand-gravel layers is described.

1) Test Ground

In order to survey the test ground core borings, standard penetration tests, measurements of modulus of deformation by Menard's pressuremeter and so forth were carried out as well as physical tests of the ground. Also in the laboratory modulus of deformation was measured by triaxial compression tests of field specimens with adjusted grading.

The test result told that the ground was composed of sand-gravel layers extending over 5 m deep, with density 2.14 t/m^3 , water content 14.0%, 60% grain size 10.0 mm, 10% grain size 0.01 mm and maximum size 50.0 mm, the composition being of 65% gravel, 21% sand, 9% silt and 8% clay.

The measurements of modulus of deformation were conducted by the pressuremeter with 56 mm and 110 mm diameter measuring pipes, respectively; two pipes were used in order to know the effect of the pipe diameter on the

measurement of the modulus of deformation.

It ranged 200-350 kg/cm² to about 6 m depth from the surface and increased to the range of 300-800 kg/cm² with depth.

The result of triaxial compression tests on the specimens sampled from the site is shown in Fig.-1, which tells that the moduli of deformation calculated by the secant corresponding 4% strain of the stress-strain diagrams are 200-500 kg/cm². The lateral pressure is primarily related to the modulus of deformation.

The specimens were prepared by compacting the material into a cylinder of 10 cm in diameter and 20 cm in height, while they had dry density 1.76 t/m³, water content 11.9%, 60% grain size 5.0 mm, 10% grain size 0.006 mm and maximum size 25 mm. The shearing constants are $c \approx 0.6$ kg/cm² and $\phi \approx 30^\circ$.

Under the surface layers of about 5 m there lied much compacted layers with slightly larger grain size and with increasing modulus of deformation with depth.

2) Test procedures

Load tests were carried out with four kinds of different circular rigid plates. They were of diameters of 37.5, 75, 150 and 300 cm. The numbers of the tests of each size were 2 for 37.5 cm test and 2 for 300 cm test conducted in 1964, 4 for 37.5, 4 for 75, 2 for 150 and 1 for 300 cm test in 1965, and 13 in all. The most interesting tests are, of course, those of 300 cm plate, so we are going to explain the outline of their test procedures.

The experimental set up and arrangement of the 300 cm load plate is shown in Fig.-2, and the assembled state, in Photo-1.

The details of the apparatuses are as follows:

- a. Load plate: prepared on the site using reinforced concrete, diameter 300 cm, thickness 100 cm.

- b. Reaction devices: 24 pressure piles of 15 m length with 12/12.4 mm PC steel wires; ultimate bearing capacity 150 tons; the piles were so made that concrete was compressed by compressed water in order that it would get attached to the wall of boring hole before hardening.
- c. Jacks: eight 300 ton oil jacks, totaling maximum load of 2,400 tons.
- d. Load girder: maximum loading capacity about 2,000 tons; 10 m long x 2 m high x 1.6 m wide; split into 5 blocks to be assembled with bolts in field as a cross girder.

The load was applied by the following cycles of loading at a rate of 40 tons/min.,

Preliminary loading	0 - 40 tons - 0
the 1st cycle	0 - 400 tons - 0
the 2nd cycle	0 - 800 tons - 0
the 3rd cycle	0 - 1,200 tons - 0
the 4th cycle	0 - 1,600 tons - 0
the 5th cycle	0 - 2,000 tons - 0

Nine dial gauges with 50 mm stroke and 1/100 mm accuracy were arranged for settlement measurements, which were made every time of pressure regulation. Reading was specified to continue until the increment of settlement in one minute amounted to less than 1% of the settlement caused by any given magnitude of load itself.

In order to avoid any sinking or shift of the fixed points for settlement measurements by dial gauges, their observation was continued throughout the tests, which revealed that the fixed points of the dial gauge holders did not sink nor shift.

3) Result of the measurements

An example of the results of 300 cm load tests is shown in Fig.-3. And also the settlement due to creep in 5, 10 and 20 minutes is seen in Fig.-4.

The modulus of deformation was calculated by the following formula of Boussinesq assuming the ground as

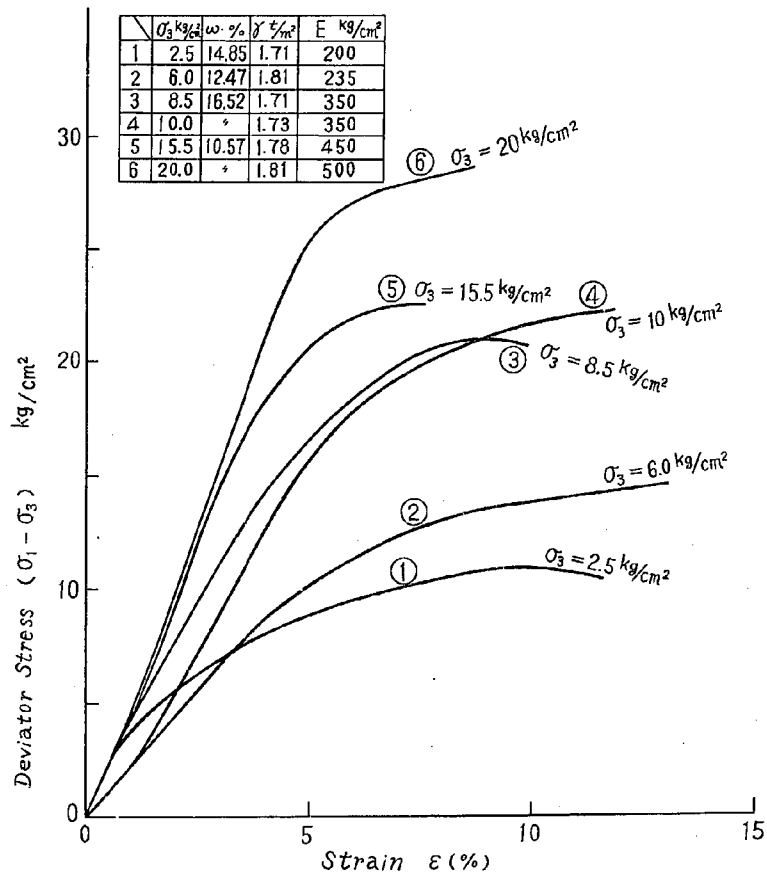


Fig.-1 Result of Triaxial Tests on Sand with Gravel

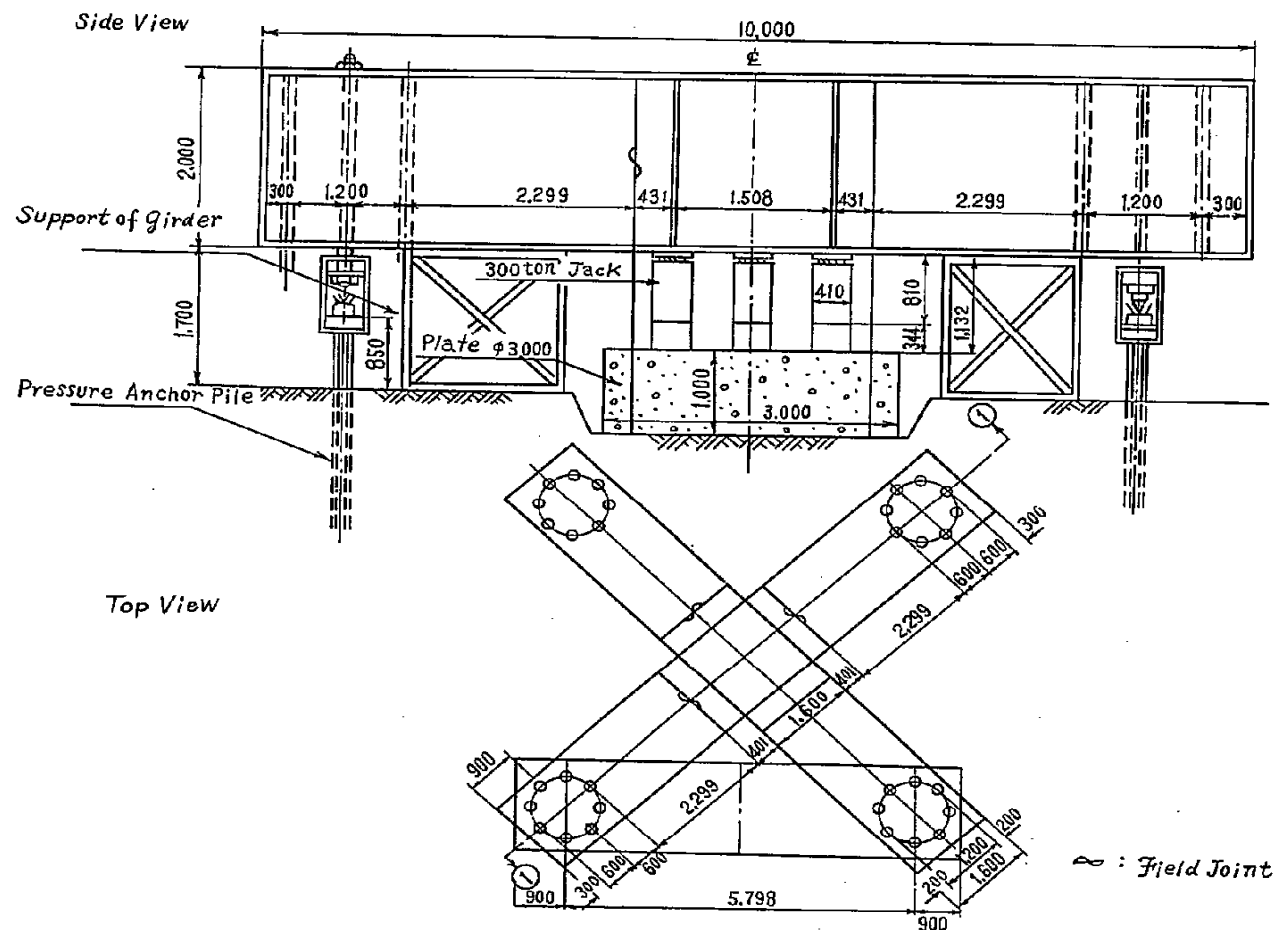


Fig.-2 Load Device

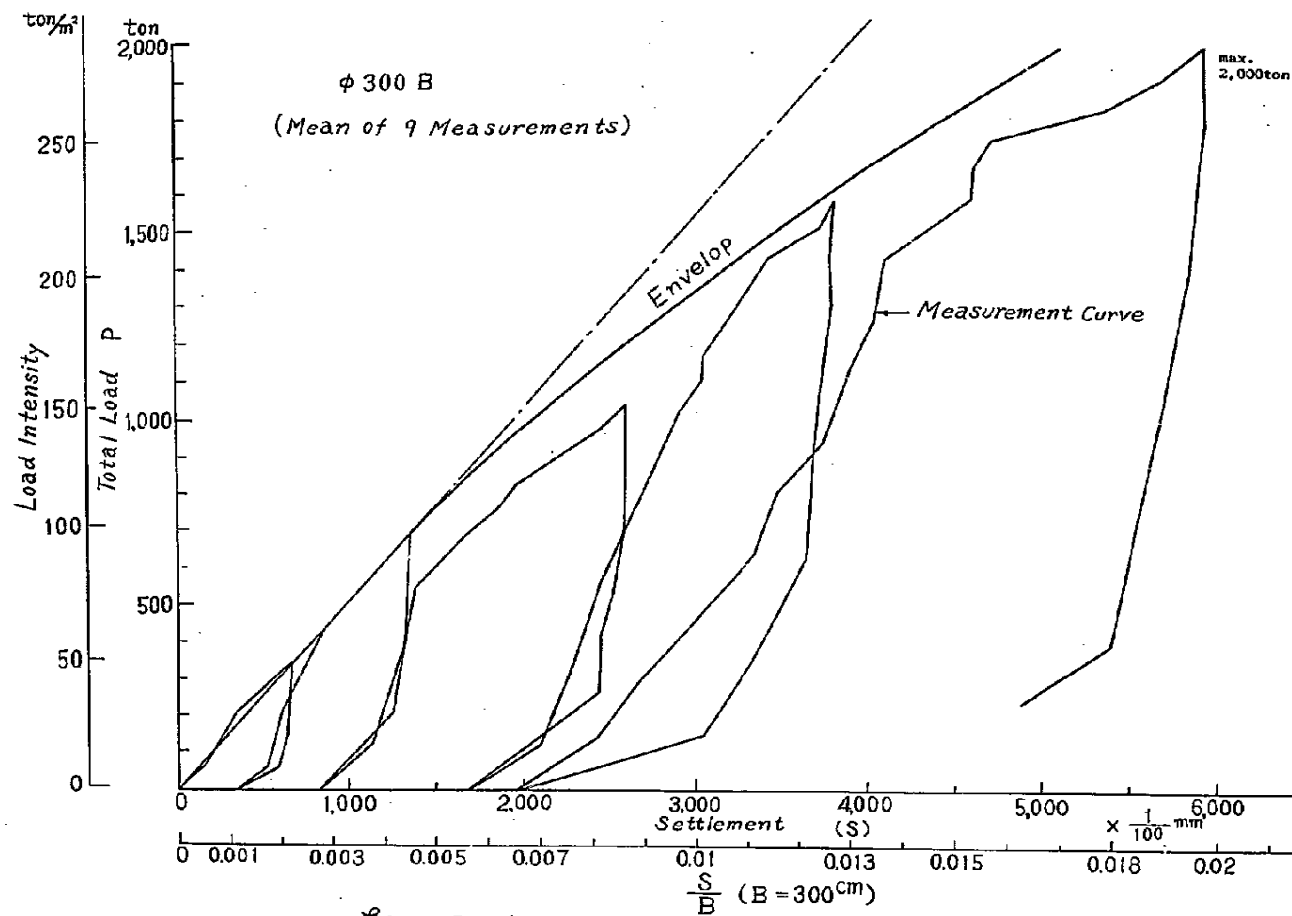


Fig.-3 Load-Settlement Curve of 300cm Plate Test

a homogeneous semi-infinite elastic mass:

$$E = \frac{\pi B(1-\mu^2)}{4} \cdot \frac{p}{s} \quad \dots\dots\dots(1)$$

where B: modulus of deformation (kg/cm²)
 μ : Poisson's ratio
 D: diameter of load plate (cm)
 p: load intensity (kg/cm²)
 s: settlement (cm)

P ton	P(kg/cm ²)	Envelope Curve			Repeated Load Curve		
		sv(cm)	$\frac{p}{s}$ (kg/cm ³)	Ev(kg/cm ²)	sr(cm)	$\frac{p}{s}$ (kg/cm ³)	Er(kg/cm ²)
350	4.95	0.7	7.07	1,431.9	0.35	14.1	2,898.7
700	9.91	1.4	7.08	1,433.9	0.60	11.7	2,362.7
1,050	14.86	2.4	6.19	1,253.6	1.00	14.9	3,009.6
1,600	22.64	3.6	6.29	1,273.9	2.20	10.3	2,084.0
2,000	28.31	5.4	5.24	1,061.3	—	—	—

Table-1 Modulus of Deformation obtained from 300 cm plate test.

In Table-1 the result of the calculation for a 300 cm load plate is shown, where Poisson's ratio is assumed to be 0.4. The modulus of deformation obtained is an apparent one, on account that the calculation is based on the elastic theory for a homogeneous mass, in spite that the ground is neither elastic nor homogeneous.

4) Consideration of the test results

According to the test results, the modulus of deformation

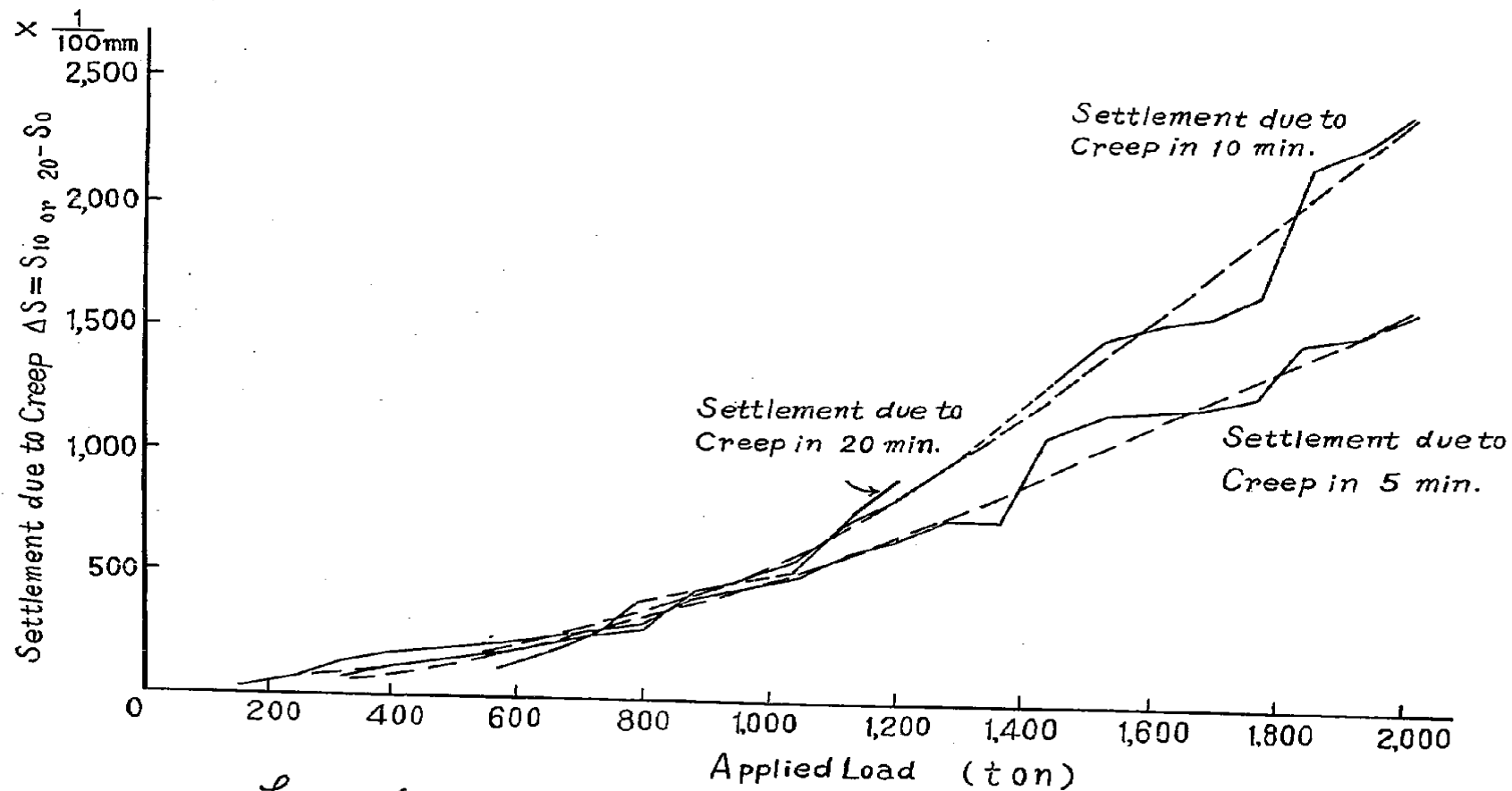


Fig.-4 Applied Load and Settlement due to Creep

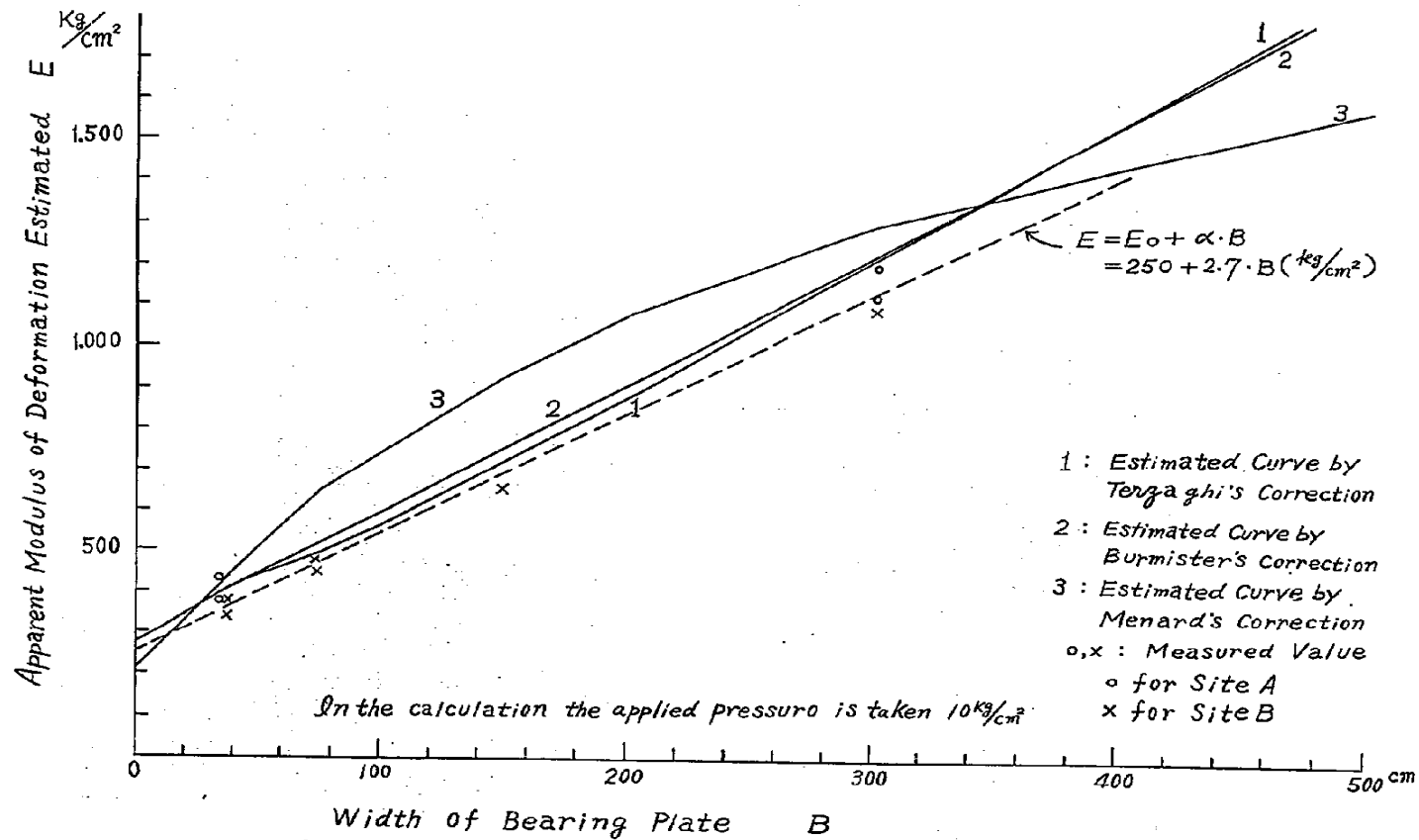


Fig.-5 Measured and Estimated Modulus of Deformation

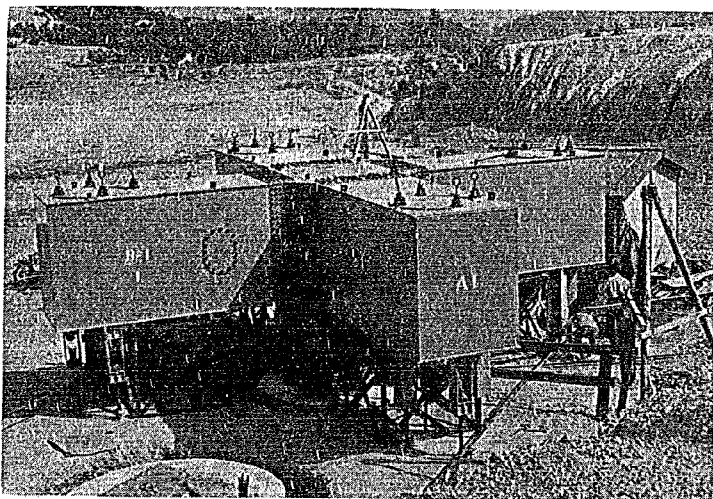


Photo-1 General view of the test

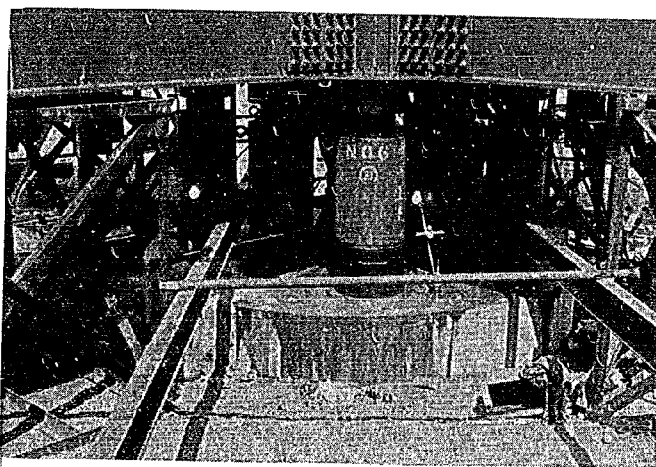


Photo-2 Loading plate and Jacks

for the ground obtained from the load tests with plates of 37.5 and 300 cm in diameter are respectively about 400 kg/cm² and 1,200 kg/cm², namely the ratio of the two is 1:3, while that of the diameter is 1:8. The reason for this is that the ground gets harder and less compressible with depth, so the apparent modulus of deformation increases with the size of the plate. In this matter Terzaghi (1943) proposed a correction formula for settlement calculation as well as Niebuhr (1939), Burmister (1962) and Menard (1962). Here is to be discussed the relationship between the authors' interpretation of the test results and the correction formulae for settlement analysis proposed by Terzaghi and others.

(a) Relationship between modulus of deformation and plate size

The modulus of deformation as relative to the load plate sizes is shown in Fig.-5, which indicates clearly a linear relationship between the modulus of deformation E and the plate width B . If we assume $E = E_0 + \alpha B$, Fig.-5 gives $E_0 = 200-250 \text{ kg/cm}^2$ and $\alpha = 2.7 \text{ kg/cm}^3$ where α is the increment factor of modulus of deformation depending on the plate width, E_0 , initial modulus of deformation of the ground, is a specific constant being independent of the load width. It is noteworthy that the value E_0 was close to those obtained or estimated by other methods such as Menard's pressuremeter, triaxial compression tests in the laboratory, or by the experimental relationship between N -value of the standard penetration test and modulus of deformation studied by E. Schultze and E. Menzenbach. 3)

From the consideration above, it was confirmed that the modulus of deformation of the sand-gravel layers mentioned was in the linear relationship up to the width 300 cm, and was expressed by $E = (200 - 250) + 2.7 B \text{ kg/cm}^2$.

But we are curious to know to what extent of plate width the above mentioned relationship will hold true. To answer this, it is necessary to discuss about the significance of the modulus of deformation obtained from the plate load test, which is influenced by the following factors such as heterogeneity of the ground in the vertical direction, lateral confined pressure in the ground,

pressure gradient, loading rate and magnitude of applied load.

The heterogeneity of the test ground in the vertical direction is, as stated above, identical for the size of the load plate. The lateral confined pressure, though complicated and involved with non-elasticity of soil, is essentially important in connection with the relationship between load width and modulus of deformation. For this problem, the results of triaxial compression tests on the specimens taken from the test ground, as was already stated, is useful for reference. The tests were executed in the range of $\sigma_3 = 2.5 \sim 20 \text{ kg/cm}^2$. Thereby the modulus of deformation calculated by the secant of the stress-strain curves increases as a primary function of lateral pressure σ_3 . If it is the case, the same tendency as in the range of $B \leq 300 \text{ cm}$ will be observed up to a considerable range of load width. The 3rd condition, pressure gradient represents the effect of the decrease of rate of stress transmitted to the ground flattening as the result of increase in the load width. Any quantitative treatment of this problem is not established yet, but it is mutually related to other conditions such as time effect and movement of water in the ground.

The above is the authors' interpretation of the test results. And if the consideration above holds, the relation $E = E_0 + \alpha \cdot B$ will be valid up to the considerable range of $B > 300 \text{ cm}$.

- (b) Relationship between test results and conventional formulae for correcting the settlement

First let us take Terzaghi's formula (4,5) which was derived from the results of small scale load tests on an artificially compacted sand layer and of settlement measurements conducted on real structures. The following formula is expressed in cm unit and converted to the relation to an arbitrary load width.

$$\frac{S_f}{S_i} = \left(\frac{B_i + 30}{B_f + 30} \right)^2 \cdot \left(\frac{B_f}{B_i} \right)^2 \dots\dots\dots(2)$$

When the Boussinesq's solution for getting settlement

is transformed to (2) to relate it to the modulus of deformation, the following formula is obtained,

$$\frac{E_s}{E_l} = \frac{B_l}{B_s} \cdot \left(\frac{B_s + 30}{B_l + 30} \right)^2 \quad \dots\dots\dots(3)$$

where Bs: width of small load plate (cm)
 B_l: width of arbitrary load plate (cm)
 Ss: settlement under Bs (cm)
 S_L: settlement under B (cm)
 Es: modulus of deformation for a small plate (cm)
 E_L: modulus of deformation estimated for a large plate (cm)

D.M. Burmister ⁶⁾ expresses the modulus of deformation for homogeneous ground under load plate as a function of depth, namely;

$$E = E_s + \frac{\partial E}{\partial z} \cdot z \quad \dots\dots\dots(4)$$

The above equation is combined with the Boussinesq's solution giving the settlement, and following relation is obtained.

$$P = \frac{1}{R} \cdot \left[s E_0 \frac{2}{\pi(1-\mu^2)} + \left(\frac{\partial E}{\partial z} \cdot s \cdot \frac{4}{\pi(1-\mu^2)} \right) \right] \quad \dots\dots\dots(5)$$

where s: settlement (cm)
 p: load intensity (kg/cm²)
 u: Poisson's ratio
 R: radius of the plate (cm)

If the $p - 1/R$ curve is plotted with s as a parameter on the basis of the results of load test with at least two different values, the equation (5) is represented as straight line and according by the value of E_0 , $\partial E / \partial z$ is found. Thus the modulus of deformation for arbitrary load width can be obtained.

L. Menard ⁷⁾ devised and practically developed the pressuremeter. The modulus of deformation, E_p, as obtained from the two-dimensional radial stress in the drill hole. The combination of Menard's formula giving

the settlement and that of Boussinesq makes the following relationship;

$$E = \frac{\frac{1}{2} \pi (1 - \mu^2) \cdot E_p}{4.5 + \frac{(1 + \mu) \cdot 30}{3} \cdot \left(\frac{1}{30R^2} \right)^{1/3}} \dots\dots\dots(6)$$

where E : modulus of deformation for an arbitrary width as corrected by the above formula (kg/cm²)

B_p: modulus of deformation by the pressuremeter test (kg/cm²)

R : foundation radius (cm)

μ : Poisson's ratio

α : factor depending on the structural characteristic of soil

The estimated curve of modulus of deformation by Terzaghi, Burmister and Menard are shown in Fig.-5, the increase of modulus of deformation is consistently linear according to Terzaghi and Burmister. It is difficult owing to the limited data available at present to judge which formula is suitable for prediction of the modulus of deformation under arbitrary load plate, but at least the following can be said.

The modulus of deformation under the foundation width of less than 3 m increases linearly, and in the range of foundation width exceeding 3 m, the tendency of linearity also seems to hold at least up to the foundation width of several 10 m, if the main cause to the increase in the modulus of deformation lies in the lateral confined pressure, i.e., the internal stress of the ground due to the increase in load width.

(5) Concluding remarks

The paper has shed some light of the deformation characteristic of the diluvial sand-gravel layers relative to the load plate width. Also the relation between the correction formulae for settlement calculation proposed by Terzaghi and others is discussed, and in spite that the results presented here

refer only to the cases with maximum plate of 300 cm, the linear relationship between modulus of deformation and load width is supposed to exist for a wider range of load width. This should be studied hereafter through settlement observations of structures on sand-gravel layers.

References

- 1) Public Works Research Institute: On the Large Scale Vertical Plate Load Tests (ϕ 300 cm), P.W.R.I. Record No. 81, June 1965 (in Japanese)
- 2) I. Yoshida, K. Komada, R. Yoshinaka and Y. Adachi: "On the Deformation Characteristics of Diluvial Sand-Gravel Layers", Tsuchi to Kiso (Soil and Foundation), Vol.14 No.12, Japanese Society of Soil Mechanics and Foundation Engineering, Dec. 1966 (in Japanese)
- 3) E. Schultze and E. Menzenbach: "Standard Penetration Test and Compressibility of Soils", Proc. of 5th I.C.S.M.F.E., 1961
- 4) K. Terzaghi: "Evaluation of Coefficients of Subgrade Reaction", Geotechnique, Vol.5, No.4, 1955
- 5) K. Terzaghi and R. Peck: "Soil Mechanics in Engineering Practice", John Wiley & Sons, 1949
- 6) D.M. Burmister: "Prototype Load Bearing Test for Foundation of structure and Pavements", Symposium on Field Testing of Soil", Special Technical Publication, No.332, A.S.T.M., 1962
- 7) L. Menard: "Rules for Calculation of Bearing Capacity and Foundation Settlement Based on Pressuremeter Tests", Proc. of 4th I.C.S.F.E., 1957