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Plugging Effect of Pile Tip
and
Bearing Capacity of Large-diameter Piles

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1. Introduction

In order to judge the plugging effect of open end piles, an investigation was made on the relationship between the resistance characteristic of soil intruded into the inside and the vertical bearing capacity of piles using model piles driven into a homogenous sand ground. Parameters determining the plugging characteristic of the pile tip were found and a calculation formula of bearing capacity applicable to large diameter piles was presented on the basis of the results obtained.

2. Test method

The model piles, the various dimensions of which are shown in Table 1, were driven with blows, measuring the quantity of soil intruded into their insides, into a soil ground (density of wet sample: 1.5 g/cm^3 , moisture content: 10%, N-value: approx. 10) which was prepared by the compaction of sand (mean particle diameter: 0.3 mm, homogeneity factor: 2.1) in an experiment pit (8 m x 5 m x 4 m). After that, vertical load tests were made and pressing-out tests of soil intruded into the inside were carried, investigating the transmission conditions of forces with attached strain gauges for the piles dug out. Finally the densities of soil were measured. By the way, it had been ascertained that the skin friction of piles was negligibly small and the resistance was considered to consist of only end resistance.

3. Results of test

The following three main subjects were clarified on the characteristics of soil intruded into the inside of open end piles by blows.

- i) The relationship between the penetrated length of the pile and the quantity of intruded soil, both being made non-dimensional by dividing them with the internal diameter of the pile is illustrated in Fig. 1 showing a nearly constant relation independent of internal pile diameter.
- ii) The ratio of shearing stress transmitted to the internal wall of the pile to the corresponding vertical stress of the soil inside the tube shows no significant difference with the magnitude of pile diameter and the point of interest inside the tube, while exhibiting scattering plot as shown in Fig. 2, but is considered to indicate a mostly constant value which is averagedly determined by the roughness of the wall surface of

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Table 1 Dimensions of model piles and the results of bearing capacity test.

	No.	Pile diameter (mm)	Wall thickness (mm)	Embedded length (cm)	Ultimate bearing capacity (Kg)	Ultimate resistance of internal soil (Kg)
Open end	1	48.6	2.4	30	255	1,800
	2	48.6	2.4	60	600	5,400
	3	48.6	2.4	100	700	-
	4	101.6	3.2	30	1,120	1,390
	5	101.6	3.2	60	1,400	13,900
	6	101.6	3.2	100	2,700	-
	7	101.6	5.7	30	1,000	750
	8	101.6	5.7	60	1,900	5,800
	9	101.6	5.7	100	3,300	-
	10	165.2	4.5	50	2,700	4,430
	11	165.2	4.5	100	5,040	>20,000
	12	165.2	4.5	150	6,000	-
	13	216.3	5.8	50	3,700	2,300
	14	216.3	5.8	100	7,500	>20,000
	15	216.3	5.8	150	9,500	-
Closed end	16	48.6	2.4	100	1,010	-
	17	101.6	3.2	100	2,900	-
	18	165.2	4.5	100	9,000	-
	19	216.3	5.8	90	10,250	-

the pile, the species of soil and the setting method of the pile. The ratio is about 0.5 in the present experiment.

iii) In the pressing-out test of internal soil, the shearing stress distribution along the internal wall of the pile at the time of ultimate resistance is shown in Fig. 3. The ordinate in this figure is made non-

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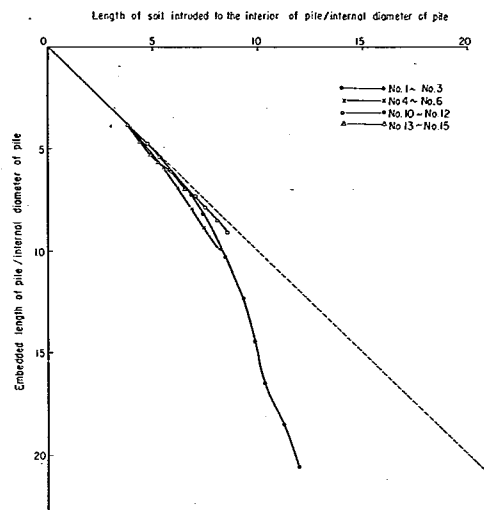


Fig. 1 Relationship between embedded length and length of soil to the interior (each being converted to ratio to the internal diameter of pile)

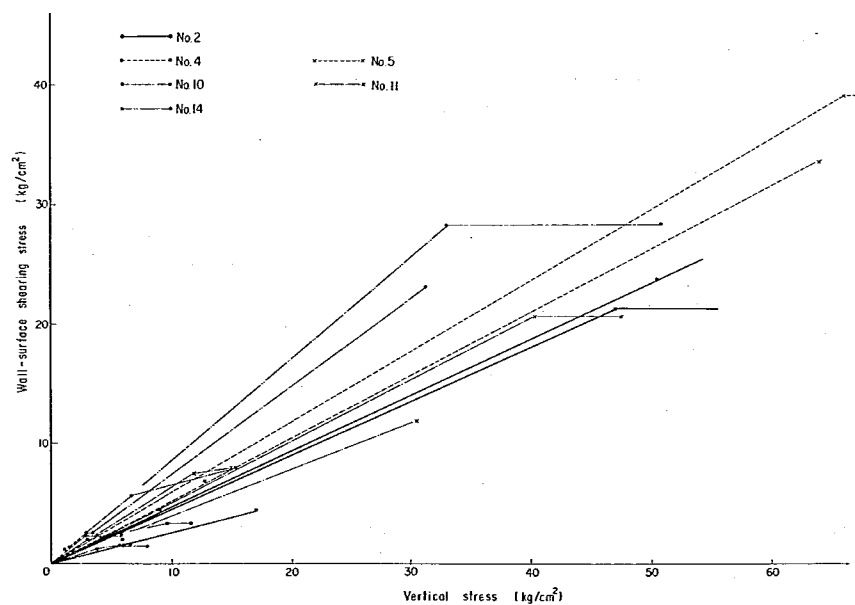


Fig. 2 Relationship of wall-surface shearing stress and vertical stress of internal soil

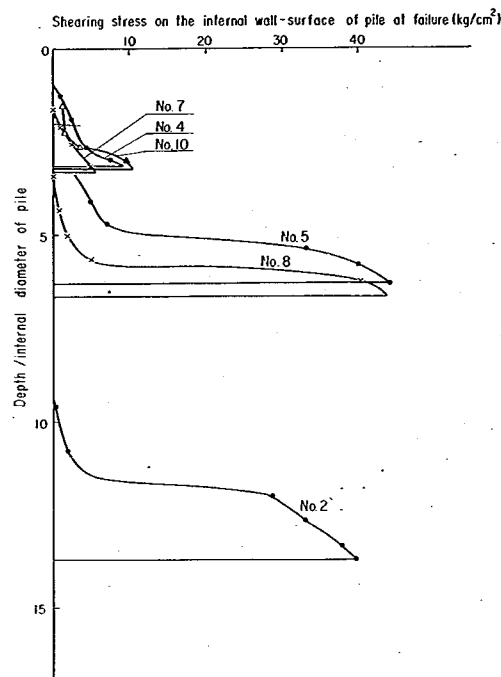


Fig. 3 Shearing stress distribution along the internal wall of pile of failure

dimensional by dividing the depth of the point of interest with the internal diameter of the pile. From the figure the tendency is recognized that the internal soil effectively contributing to the resistance is confined to a certain range from the pile end, and as the embedding ratio (embedded length/internal pile diameter) increases beyond a certain degree of amount, the shearing stress (τ) levels off at a maximum value ($\tau_{\max}$) entering into the region of plasticity ($\tau = \tau_{\max}$). It is estimated that the saturation of the shearing stress appears because the shearing occurs not on the internal wall of the pile but in the interior of soil close to the wall surface. Accordingly $\tau_{\max}$ results from the shearing strength proper to the ground, namely, is unambiguously determined by the species of soil. In the present sand ground $\tau_{\max} = \text{approx. } 40 \text{ kg/cm}^2$.

It is considered from the above results that as controlling factors of the resistance of soil intruded into the inside, the three of the transmission ratio of vertical stress to the pile wall in the form of shearing stress, the transmittible maximum shearing stress and embedding ratio are principal and it is, moreover expected that as far as the embedding ratio is comparatively small and the shearing stress of the end of the pile wall remains below the maximum value, the ultimate resistance force increases exponentially against the embedding ratio and after the shearing stress at the end of the pile reaches the maximum value, it increases in proportion with embedding ratio on the basis of the consideration of the balance of forces inside the pile tube and the experimental facts. The dotted line shown in Fig. 4 shows the ultimate resistance force per unit area of internal soil as a function of embedding ratio on the basis of such consideration.

On the other hand, the bearing capacity at the end in the vertical load test is plotted against the embedding ratio in Fig. 4, showing the increasing tendency of the bearing capacity of ground at the pile tip denoted as a solid line. The comparison of this bearing capacity with the change (dotted line) of the ultimate resistance force of the internal soil described above allows

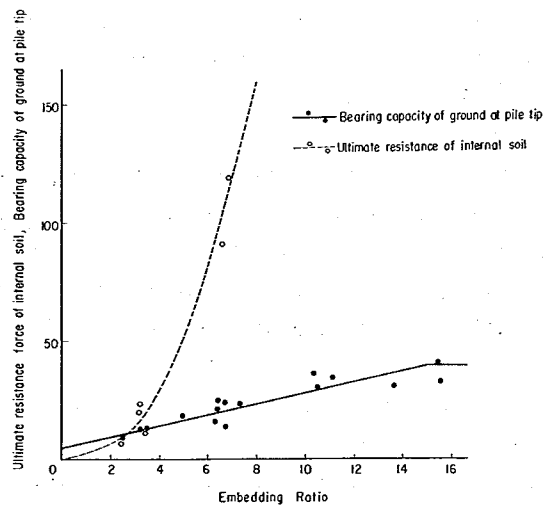


Fig. 4 Ultimate resistance force of internal soil and ultimate bearing capacity of ground at pile tip

the estimation of the plugging effect of the pile tip. In the present experiment using homogeneous sand ground (N-value; approx. 10) the embedded length giving sufficient plugging effect against the strength of ground at the pile tip was about 2.5 times of the pile diameter.

4. Bearing power of large diameter piles

In general, bearing capacity formula belonging to Meyerhof's are currently used in this country for giving the method to calculate the vertical bearing capacity of foundation piles. Namely, the end bearing capacity of piles are considered as.

$$P = 40 \times N \times A \text{ (t)}$$

where N: N-value

A: Cross sectional area of pile tip

While this formula can be fairly well applied to the measured values for middle-or small diameter piles (less than the diameter of 600 mm), the computed values become significantly larger than the measured values for piles of larger diameter such as these having diameters from 1,000 mm to 1,500 mm, recently much employed.

The reasons of this are

- (1) In large diameter piles, embedding ratio into the bearing stratum is deficient compared with the pile diameter causing the insufficient development of strength of the pile tip ground.
- (2) Problems of plugging effect occur

Consequently, on the experimental results above stated, the following calculation of the end bearing capacity of open end piles is recommended, considering the above two factors, namely the bearing capacity of pile tip ground is estimated as 40N as far as the embedding ratio rendering the shear failure surface kept inside the bearing stratum is assured and as being lowered on the basis of the solid line of Fig. 4 in the event of smaller embedding ratio than the above value. Moreover, the ultimate resistance force of the internal soil of piles is given by the direct application of the curve shown in broken line of Fig. 4 and the smaller of these is regarded as the end bearing capacity of open end pile. Accordingly the end bearing capacity of steel pile piles (open-ended) can be obtained from Fig. 5.

Another result of investigation revealed that the following values are appropriate for the skin frictional force of steel pipe piles.

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Table 2. Skin frictional force of steel pipe pile

Sandy soil	Clayey soil
$= N/5 \text{ (t/m}^2\text{)}$	$= C \text{ or } N \text{ (t/m}^2\text{)}$
$(\leq 10 \text{ t/m}^2)$	$(\leq 10 \text{ t/m}^2)$

C: Cohesion

N: N-value

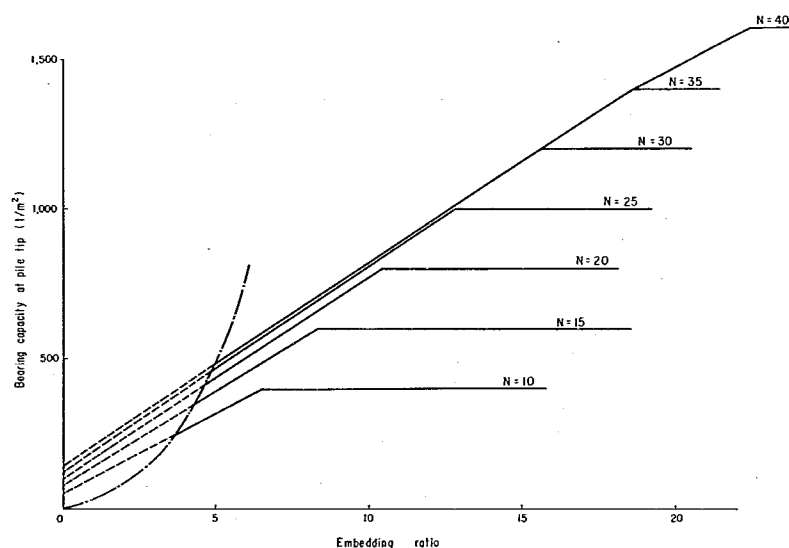


Fig. 5 End bearing capacity of pile

As a result, the comparison of the calculated ultimate bearing capacity as the sum of the end bearing capacity and the skin frictional force with the ultimate bearing capacity obtained in the load test performed actually on steel pipe piles indicates the results shown in Fig. 6 (1) ~ (3), giving fairly good agreement of both even for large diameter piles.

5. Postscript

We are planning to supplement the present results by continuing further experiments on the resistance of soil intruded into the interior of piles.

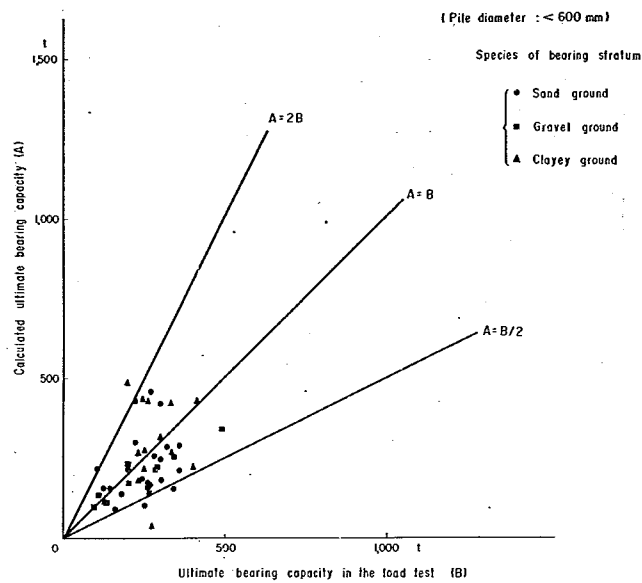


Fig. 6-(1) Comparison of calculated bearing capacity with load test result

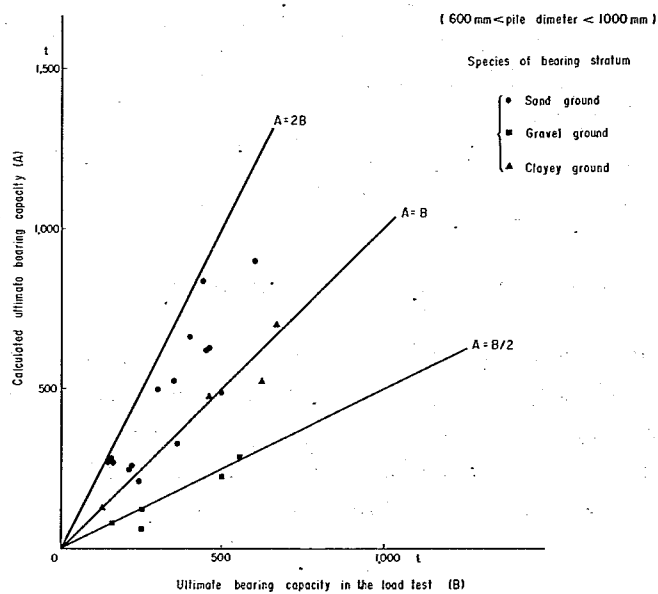


Fig. 6-(2) Comparison of calculated bearing capacity with load test result

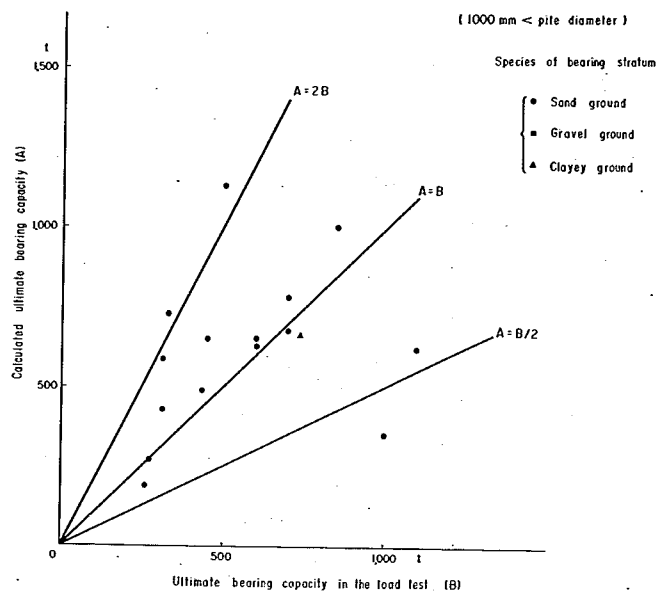


Fig. 6-(3) Comparison of calculated bearing capacity with load test result