ESTIMATING THE ULTIMATE TIP LOAD OF A BORED PILE AND APPLICABILITY OF AN EMPIRICAL FORMULA

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This study was conducted to assess the resistance coefficient of an empirical formula often used to estimate the static vertical ultimate load at the tip of bored pile. Ultimate tip load was defined as the load at which a given pile attains a settlement that is equal to 10% of its diameter (Such load is known as the standard bearing capacity of a pile). Data taken from each of a series of loading tests were analyzed in detail, assuming that they follow a Weibull distribution curve. Extent was determined to which such loading test should be conducted so that data therefrom be effectively used to estimate, with a reasonable accuracy, the ultimate load of a pile at its tip in terms of its settlement/diameter ratio also at its tip. Three different average N-values were determined of a given soil each in a different way. The coefficient of resistance was then determined for an empirical formula, by dividing the tip load as measured by each of the three different N-value so as to determine which N-value can be used to the best effect.

Key words: bored precast pile, case history vertical loading test, load-settlement curve, tip bearing capacity , standard penetration test .

Introduction

Loading test is seldom conducted on a pile to a load large enough to allow its ultimate load to be clearly identified. If sufficient data are not available, as often is the case, ultimate load needs to be estimated of a pile by extrapolating the load-settlement curve as determined through a loading test conducted on such pile. Methods have been proposed to estimate such ultimate load by assuming a mathematical model, including an exponential relationship, to represent data from a loading test[1]. The technique proposed by Van der Veen[2] and that worked out by Uto et al[3] are typical of such methods that have widely been used.

Based on a technique to accurately estimate the ultimate bearing load of an impact-driven open-end steel-pile by applying a statistical analysis to data from a vertical loading test as conducted on such pile, Matsuo et al[4] proposed a method to work out an empirical formula to determine its static bearing capacity. Yamagata et al [5],[6] undertook a comprehensive study on the ultimate tip load of cast-in-situ and bored piles by applying a statistical analysis to the data taken from a series of loading tests on such piles, deriving a correlation between ultimate load at their tip and the N-value of the soil there.

Meant to offer possible methods, as well as to demonstrate their validity, with which to work out empirical formulas enabling us to determine the resistance from the soil at the tip of a pile and the force arising from the friction along its length, these proposals and studies proved to be a great deal of improvement in pile foundation design practice. Horiuchi et al[7] proposed to another method estimate the ultimate tip load of a pile with a reasonable accuracy by assuming that the load-settlement relationship follows a Weibull distribution curve. In spite of such proposals and studies, not enough work has been conducted to data to estimate the ultimate tip load of a bored pile or to determine the correction factor for empirical formulas available to calculate such load.

This paper describes the study conducted to work out the correction factor of an empirical formula to determine the static vertical bearing capacity of a long bored pile. Data were used from a series of loading test that had been conducted elsewhere on seven different types of pile. Details are as follows:

(1) Relationships were examined between load and settlement/diameter ratio as well as load and residual-settlement/diameter ratio, both at pile tip and pile top

as worked out by using the results form a multi-cycle loading test conducted on each of the piles, assuming that both of such relationships follow a Weibull distribution curve[3].

(2) In reference to such relationships, extent was determined of the load to which a loading test should be conducted so as to accurately estimate the ultimate bearing load of a pile tip , defined as that at which its settlement reaches 10% of its diameter.

(3) Applicability was examined of an empirical formula widely used to calculate the vertical bearing capacity of a bored pile, in reference to the N-value and the settlement/diameter ratio. In doing so, three different types of average N, N_1 and N_2 were used: $\bar{N}$ was determined as corresponding to the range of depth between 4D above and 1D below pile tip (as currently used), N_1 as measured over a range of depth from 1D above to 1D below pile tip, and N_2 as determined over an interval of depth between pile tip and 1D below there, so as to incorporate the recently prevailing concept on mechanics of soil and also to see which of the N-values can be adopted to the best effect.

(4) Coefficient of resistance was derived for the empirical formula, by dividing the tip load as measured by each of the three different N-values.

METHOD TO ESTIMATE THE ULTIMATE TIP LOAD AND SAMPLE PILES

In estimating the ultimate tip load of a bored pile, its load-settlement characteristic was assumed to take a Weibull distribution curve, as had been proposed by Uto[3]. The curve can be expressed by the following equation:

$$Ro=(Ro)u\ [1-\exp\{-So/Sy)^{m}\}] \qquad (1)$$

where Ro is the load applied on pile top; (Ro)u, the ultimate pile top load, So the settlement at pile top, Sy the settlement (when Ro is equal to the yield load Ry, the value of Ry can be obtained as 0.63(Ro)u); m(>0), the displacement index (m was assumed to be equal to 1 in this study).

For the purpose of this study, data were taken from the loading tests conducted on seven long concrete precast piles, each bored into a predrilled hole by using an auger passing through its hollow at each of the five different sites. All the piles, except one, were of the type provided with a friction cut to improve load transmitting efficiency from their top to tip, and had been bored into a number of different types of soft soil in conformity with the purpose of this study. A pile without such friction cut was also included among the sample piles to compare its load bearing capacity with those of the other piles provided with a friction cut. To ensure reliable results, all the sample piles, though relatively few in number, were chosen from among:

(1) those which had been installed with due care so that they might provide as accurate a set of data as possible,

(2) those to which a depth gauge and a set of strain gauges had been attached so that the resistance from the soil at their tip and the friction along their circumference could be determined separately,

Table.1 General Description of Sample piles and their installation

sample pile	pile Instration	pile Diameter(mm) Top	Tip	pile penetration depth(m)	Tipe of soil	Load transmitting ratio
A_1	RODEX	800	1000	49	gravel and bould	84
A_2	NAKS	1000	1000	49	gravel and bould	95
B	ST-RODEX	450	450	43	sand	81
C	NAKS	1000	1000	54	sand and gravel	82
D	ATRAS	800	800	51	sand	82
E_1	ST-RODEX	600	600	40	gravel and sand	24
E_2	ST-RODEX	600	600	40	gravel and sand	78

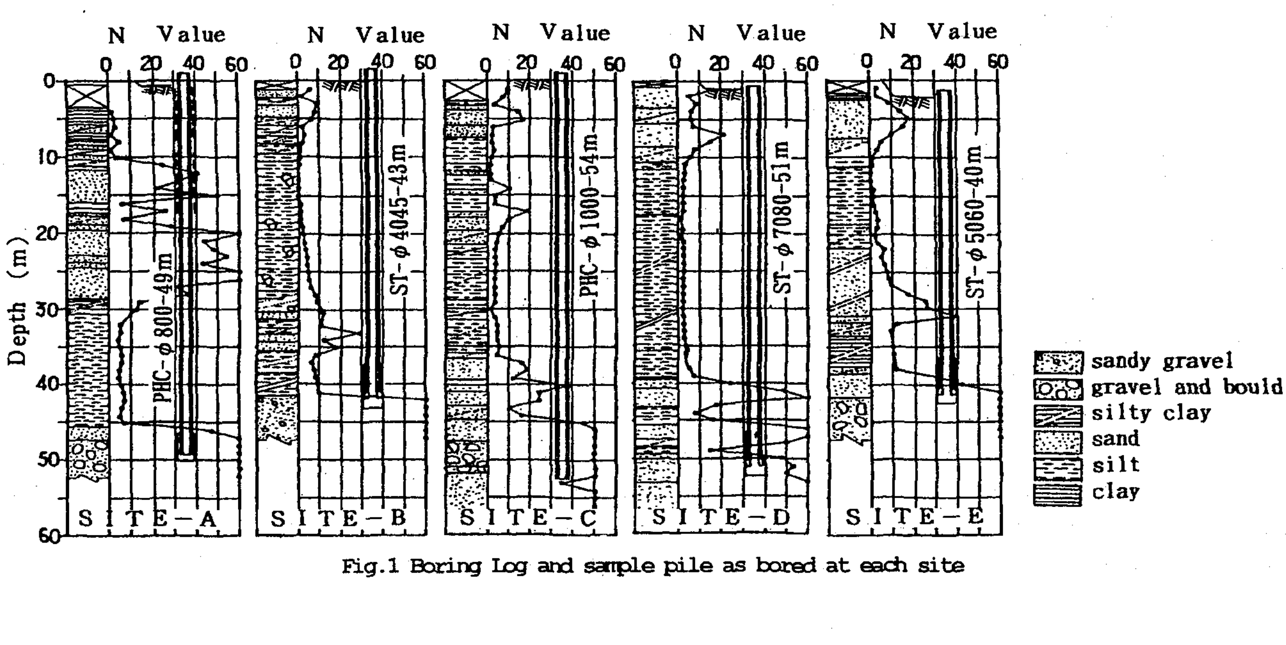


Fig.1 Boring Log and sample pile as bored at each site

(3) those which had been tested to a relatively large load or settlement , and had attained a top-to-tip load transmitting ratio greater than 80% so that a high degree of accuracy could be obtained in the results as estimated by using the proposed method, and

(4) those which provided a relatively consistent set of information on soil conditions and installation method.

Given in Table 1 are the diameters, installation method, penetration depth into load bearing layer, type of soil, and the top-to-tip load transmitting ratio at the maximum test load for each of the seven sample piles. Strain gauges were attached to every pile at a height of 0.5 to 1.0m from its tip. Shown in Fig.1 are the boring log at each site along with the respective sample pile as installed. The vertical loading tests were carried out in accordance with the Standard the Japanese Society of Soil Mechanics and Foundation Engineering[1).

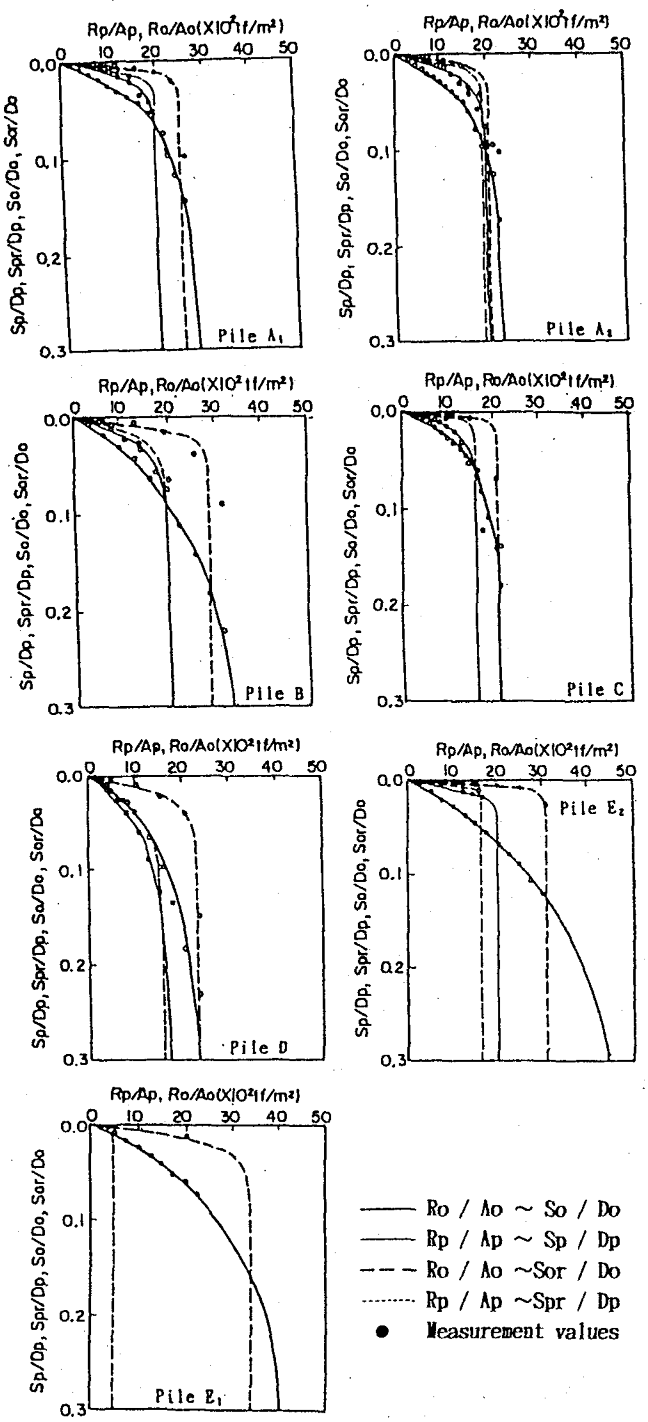


Fig.2 Load Settlement Curve at Pile Top and Pile Tip

ESTIMATING THE ULTIMATE TIP LOAD

Fig.2 shows seven diagrams each containing four curves representing the relationship between unit load or load per unit area (Ro/Ao) and settlement/diameter ratio(So/Do), unit load(Ro/Ao) and residual-settlement/diameter ratio(Sor/Do), both at pile top, as well as those between unit load (Rp/Ap) and settlement/diameter ratio(Sp/Dp), unit load(Rp/Ap) and residual-settlement/diameter ratio(Sor/Do), both at pile tip, for each of the seven sample piles respectively.

Shown in Fig.3 are curves each representing the relationship between unit load(Ro/Ao) and residual-settlement/diameter ratio(Sor/Do) at pile top as well as that between unit load (Rp/Ap) and settlement/diameter ratio (Sp/Dp) at pile tip for each of the sample piles.

By observing these two figures, it can be noted that:

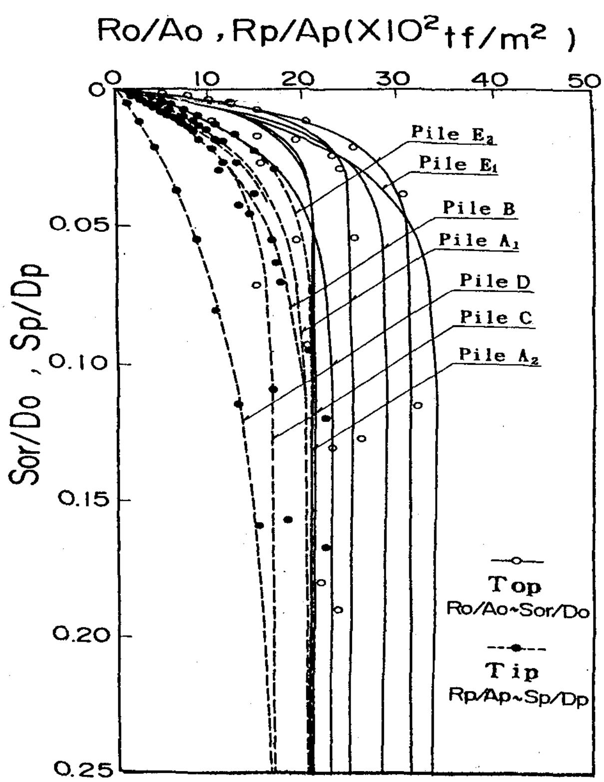


Fig.3 Ro/Ao~So/Do and Rp/Ap~Sor/Do relationship for each of the seven sample piles

(1) In general, the experimental data taken at pile top are in fairly good agreement with the respective curves representing Eq. (1), and so are the ultimate unit top loads (Ro/Ao)u as calculated acordinate the Eq. (1) with the corresponding ultimate loads as measured, either when settlement/diameter ratio exceeds 20% or as residual-settlement/diameter ratio becomes larger than 15% at pile top. Data taken at pile tip are also in good agreement with the respective theoretical curve. No significant difference is seen between ultimate tip loads (Rp/Ap)u as calculated and those as measured, either when the settlement/diameter ratio exceeds 10%, or as the residual-settlement ratio becomes larger than 6% or 7% at pile tip. In every case, however, a substantial discrepancy appears between the maximum unit tip load as measured and the corresponding load as calculated with Eq. (1) using data at a settlement diameter ratio or residual-settlement/diameter ratio smaller than those specified above.

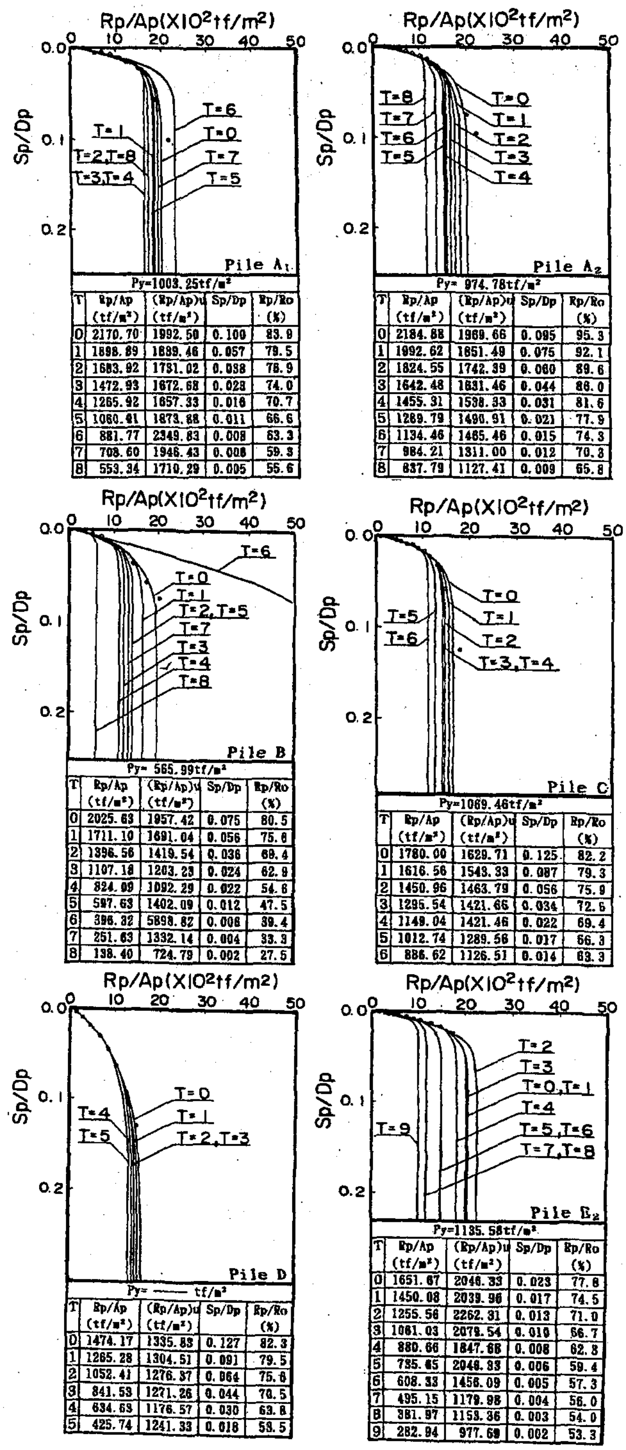
(2) The ultimate unit loads as calculated in accordance with Eq. (1) by using load-settlement data taken at pile top, and also their scatter, are generally greater than those calculated by using the corresponding data taken at pile tip, indicating that it is inadvisable to determine such ultimate loads by assuming that the load-settlement characteristics of a pile at its top be closely related to that at its tip. The inadvisability of using load-residual-settlement data taken at the top of a pile to estimate its ultimate tip load has already been pointed out by Yoshinari[8] who asserted that such data are not directly related to settlement behavior at its tip in a direct manner.

(3) Even with the sample piles provided with a friction cut, significant difference is seen between the ultimate unit tip loads as calculated by applying data taken at their top and those obtained by using taken at their tip, indicating that they too are subject to friction. Such difference can be regarded as arising from the difference in pile installation technique and/or conditions, in extent to which each sample pile was provided with a friction cut, in type of soil as well as pile penetration into respective load bearing layer, and also in compressive strength of soil at pile pedestal.

ACCURACY OF ESTIMATED ULTIMATE TIP LOAD

Upon proposing a new method to estimate the ultimate tip load of a bored pile without a loading test conducted to, or close to its maximum bearing capacity, an assessment is needed to verify its validity. From practical point of view, this implies that the extent to which such loading test should be carried out on a given pile must be determined so that its ultimate tip load can be estimated with a reasonable accuracy.

In order to determine such extent, ultimate tip load of a pile was calculated by substituting its load-settlement data, taken at each of the load levels as had been applied during its loading test, from the maximum (Rp)max down to minimum, into Eq. (1) and the variation in the results was



Pile A1: Py=1003.25tf/m²

T	Rp/Ap (tf/m²)	(Rp/Ap)u (tf/m²)	Sp/Dp	Rp/Ro (%)
0	2170.70	1992.50	0.100	83.9
1	1898.89	1889.46	0.057	79.5
2	1683.92	1731.02	0.038	78.9
3	1472.93	1672.68	0.028	74.0
4	1265.92	1657.33	0.018	70.7
5	1060.41	1873.88	0.011	66.6
6	881.77	2349.83	0.008	63.3
7	708.60	1946.43	0.008	59.3
8	553.34	1710.29	0.005	55.6

Pile A2: Py= 974.78tf/m²

T	Rp/Ap (tf/m²)	(Rp/Ap)u (tf/m²)	Sp/Dp	Rp/Ro (%)
0	2184.88	1969.66	0.095	95.3
1	1992.62	1851.49	0.075	92.1
2	1824.55	1742.39	0.060	89.6
3	1642.48	1631.46	0.044	86.0
4	1455.31	1538.33	0.031	81.6
5	1289.79	1490.91	0.021	77.9
6	1134.46	1485.46	0.015	74.3
7	984.21	1311.00	0.012	70.3
8	837.79	1127.41	0.009	65.8

Pile B: Py= 565.99tf/m²

T	Rp/Ap (tf/m²)	(Rp/Ap)u (tf/m²)	Sp/Dp	Rp/Ro (%)
0	2025.63	1957.42	0.075	80.5
1	1711.10	1691.04	0.056	75.6
2	1396.56	1419.54	0.036	69.4
3	1107.18	1203.23	0.024	62.9
4	824.09	1092.29	0.022	54.6
5	597.63	1402.09	0.012	47.5
6	396.32	5898.82	0.006	39.4
7	251.63	1332.14	0.004	33.9
8	138.40	724.79	0.002	27.5

Pile C: Py=1069.46tf/m²

T	Rp/Ap (tf/m²)	(Rp/Ap)u (tf/m²)	Sp/Dp	Rp/Ro (%)
0	1780.00	1629.71	0.125	82.2
1	1616.56	1543.33	0.087	79.3
2	1450.96	1463.79	0.056	75.9
3	1295.54	1421.66	0.034	72.6
4	1149.04	1421.46	0.022	69.4
5	1012.74	1289.56	0.017	66.3
6	886.62	1126.51	0.014	63.3

Pile D: Py= —— tf/m²

T	Rp/Ap (tf/m²)	(Rp/Ap)u (tf/m²)	Sp/Dp	Rp/Ro (%)
0	1474.17	1335.83	0.127	82.3
1	1265.28	1304.51	0.091	79.5
2	1052.41	1276.37	0.064	75.6
3	841.53	1271.26	0.044	70.5
4	634.63	1176.57	0.030	63.8
5	425.74	1241.33	0.018	53.5

Pile E2: Py=1135.58tf/m²

T	Rp/Ap (tf/m²)	(Rp/Ap)u (tf/m²)	Sp/Dp	Rp/Ro (%)
0	1651.67	2046.33	0.023	77.8
1	1450.08	2039.96	0.017	74.5
2	1255.56	2262.31	0.013	71.0
3	1061.03	2079.54	0.010	66.7
4	880.66	1847.66	0.008	62.8
5	735.45	2046.93	0.006	59.4
6	608.33	1456.09	0.005	57.3
7	495.15	1179.98	0.004	56.0
8	381.97	1153.36	0.003	54.0
9	282.94	977.69	0.002	53.3

Fig.4 Load Settlement Curve of Pile Tip by Eq. (1)

analyzed by comparing them with the corresponding actual maximum tip load as measured. The diagrams given Fig.4 show the relationships between ultimate load (Rp/Ap) and settlement/diameter ratio(Sp/Dp), both at pile tip, representing the results worked out for sample pile A2 in the manner described above, along with the measured values. A number T is attached to each curve representing the estimated result, indicateing the respective load level, counted down from the maximum, at which data were taken to work it out (T=0 when Ro=(Ro)max). The data shown with symbol (●) are the measured values. Given in the table included in Fig.4 are the values for the ultimate tip load (Ro/Ap) as measured, the ultimate load (Rp/Ap)u as estimated by using Eq.(1), and the settlement/diameter ratio (Sp/Dp) as well as the ratio at which load was transmitted from pile top to pile tip, all at each load level.

It can be seen in the diagrams and tables that the ultimate tip load (Rp/Ap)u as estimated varies substantially depending on the load level at which data were taken.

Fig.5 shows the variation in percentage error in ultimate tip loads as estimated at different load levels, represented in terms of settlement/diameter ratio(Sp/Dp) at pile tip (for six types of sample). The error was calculated by using the following equation:

$$\text{Error}(E)=\{(Rp)\max-(Rp)\max\text{-}n/(Rp)\max\}\times 100(\%) \qquad (2)$$

where (Rp) max is the maximum tip load as measured, (Rp)max-n the maximum tip load as estimated by using data taken at the nth loading level counted down from 0 ((Rp)max corresponding to 0 loading level).

It is seen in Fig.5 that the error in the ultimate tip load as estimated becomes less than 10% as the settlement/diameter ratio(Sp/Dp) exceeds 0.075 at pile tip.

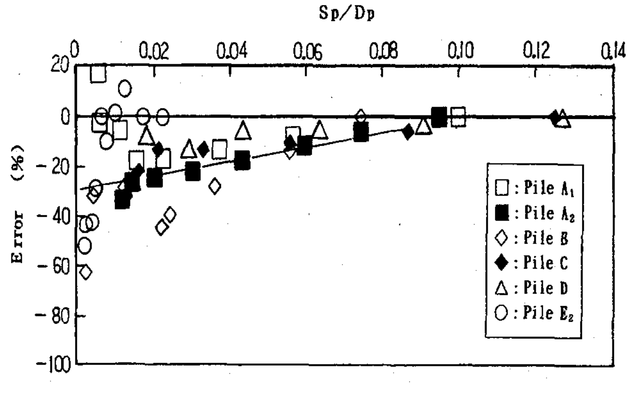


Fig.5 Error of Estimate and Ratio of Settlement to Pile Tip Diameter

The error is further reduced to less than 5% if data are taken at a load level at which settlement/diameter ratio becomes greater than 0.1 at pile tip. It is also observed that the ultimate tip load of a pile, assumed to be the one at which its settlement/diameter ratio(Sp/Dp) becomes 0.1 at its tip, can be estimated with an error no greater than 15% by using data taken at a load level at which its settlement/diameter ratio exceeds 0.075 at its tip. It has thus becomes clear that, in order to estimate the ultimate tip load of a given pile with a reasonable accuracy by using Eq.(1), data are needed of a loading test that has been conducted to a load level at which its settlement/diameter ratio attains at least 0.075.

EMPIRICAL EQUATION TO CALCULATE STATIC LOAD BEARING CAPACITY OF A BORED PILE

Given below is a set of empirical equation that has widely been used to calculate the ultimate vertical statics load bearing capacity of a bored pile (Architectural Institute of Japan 1988):

$$Ru=Rp+Rf \qquad (3)$$

where Ru is the ultimate bearing capacity of the pile; Rp, the ultimate resistance at pile tip; Rf, the ultimate friction resistance around pile[9].

The tip resistance of pile can be represented by the following equations.

$$Rp=\alpha\cdot\bar{N}\cdot Ap \qquad (4)$$

where α is the reduction factor at pile tip, N, the average $\bar{N}$-value taken over a range of depth between 4D above and 1D below pile tip; Ap, the cross sectional area of the pile at its tip.

In many study that has hitherto been conducted on vertical statics load bearing capacity of a pile, effort has been focused on determining the coefficients α for Eq.(4) respectively. Simple equations have been proposed to data, for these coefficients, in terms of average N-value of the soil as determined by a standard penetration test(SPT) at a given site and the cross-sectional area of a given pile at its tip. Typical of such equation, particularly with regard to the Eq.(4) above, are $30\bar{N}\cdot Ap$ for impact driven piles, $25\bar{N}\cdot Ap$ for piles installed by authorized boring methods (Building Center of Japan[10]), and $20\bar{N}\cdot Ap$ for those installed by unauthorized boring methods. Such empirical approaches, practical though, can hardly be regarded as being theoretically meaningful. Notwithstanding the foregoing, it was decided to adopt Eq.(4) in its basic form for the purpose of this study because of its wide use and relatively good agreement with the ultimate tip loads defined in the preceding chapter. Subsequent study was conducted to assess its applicability in terms of load-settlement relationship by examining how good an agreement could be attained between the equation and the ultimate tip load as determined by using the method herein proposed.

AVERAGE N-VALUE AND APPLICABILITY OF THE EQUATION

According to Eq. (4), the ultimate tip load of a pile depends on the coefficient α and average N-value $\bar{N}$ of the soil around its tip. Three different types of average N-value, $\bar{N}$, N1 and N2 were available for this study as shown in Fig 6, which corresponds to that in SPT. Dp is pile tip diameter. $\bar{N}$ is widely used in current pile-foundation design practice, while N1 is the one whose use is recommended in this paper.

Table2. Regression Line of (Rp/Dp)~N-value

	(Rp/Dp)u~N	(Rp/Dp)u~N1	(Rp/Dp)u~N2
coefficient(α)	32.8(31.7)	25.2(26.2)	25.1(26.2)
Standard deviation(σ)	2.51(9.60)	1.34(6.98)	1.85(7.93)
Variation(V)	0.077(0.303)	0.053(0.267)	0.074(0.303)

*The figures in brackets ( ) Yamagata and others (1992) Preboring piles method

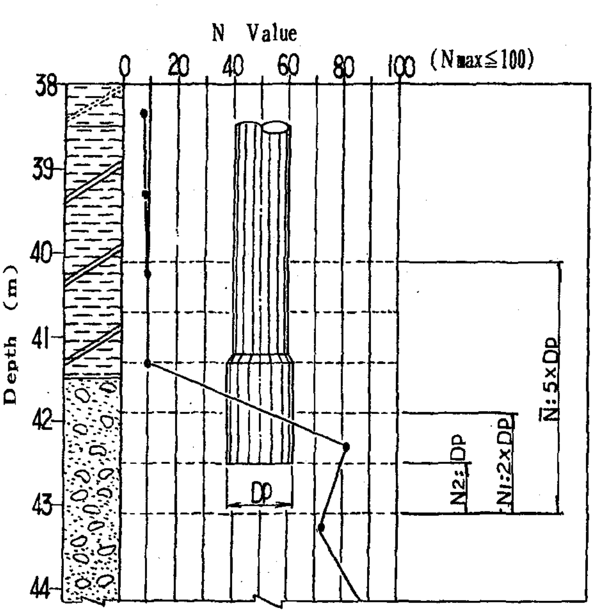


Fig.6 Three different N-values

In every case, when average N-value reached 50 at a pile penetration depth less than 30cm from the upper limit of respective range, an equivalent value was determined by extrapolating it to a depth of 30cm in proportion to the penetration. Further more, the maximum value of each N value is limited within 100. Table 2 shows the average values of coefficient α {=(Rp/Ap)u/N} as calculated by dividing the tip load determined through loading test by each of such average N-values. Also given in Table 2 are the standard deviation δ of the coefficient α as well as its variation V for every such average N-value indicating its scatter. Shown in the same Table, are the results as reported by Yamagata et al [6] from their study on precast piles installed by boring method.

It can be observed in Table 2 that, of the three values, either N1 or N2 can be taken for average N value to good effect when calculating the ultimate tip load of a bored pile by using Eq.(4), as either of them gives a value of α close to 25, as often used in practice to calculate such load for a pile installed by an authorized boring method. This may have been due to the fact that, the data used were from piles that had attained a load transmitting efficiency exceeding 80%. Of the two, however, N1 appears to be more suitable than N2 for the purpose, the variation, and consequently the scatter, being smaller with the former than with the latter.

Analysis was subsequently conducted to examine how good an agreement can be obtained between Eq.(4) and those determined with the herein proposed (Rp/Ap)u by using two of the average N-value, $\bar{N}$ and N1. For the purpose the ultimate tip loads (Rp/Ap)u as estimated by using data taken at each of the various load levels were plotted against $\bar{N}$ in Fig.7 and N1 in Fig.8. The straight lines shown in these figures represent Eq.(4), with α as parameter.

Looking at these figures, it can be noted that:

(1) when $\bar{N}$ is taken for average N-value and 25 (a value often used for piles bored by an authorized method) for α, Eq.(4) shows a good agreement with the estimated results, provided that the settlement/diameter ration (Sp/Dp) as determined by a loading test is approximately 0.04 at pile tip. With α=20 (a value normally used for piles bored by an unauthorized method), Eq.(4) is also in good agreement with the estimated results, when the settlement/diameter ratio determined by loading test is around 0.04 at pile tip.

(2) when N1 is taken for average N-value and with α =25, Eq.(4) is seen to be in good agreement with the estimated results, provided that the settlement/diameter ratio (Sp/Dp) as determined by loading test is over 0.06

at pile tip. Also when α=20is used, Eq.(4) agrees well with the estimated values, if settlement/diameter ratio is about 0.04 at pile tip.

(3) the value for α with which Eq.(4) using $\bar{N}$ would show a good agreement with the results as estimated at a settlement/diameter ratio (Sp/Dp) over 0.075 at pile tip, is about 33.3. This is approximately 1.3 time greater than 25, the standard value of α to be used with for Eq.(4) when calculating the ultimate tip load of a pile bored by an authorized method. Using N1 for N, however, such value for α becomes approximately 25.

From the foregoing, it is now evident in an quantitative manner that the degree of agreement or otherwise between Eq.(4) and the corresponding ultimate tip loads as

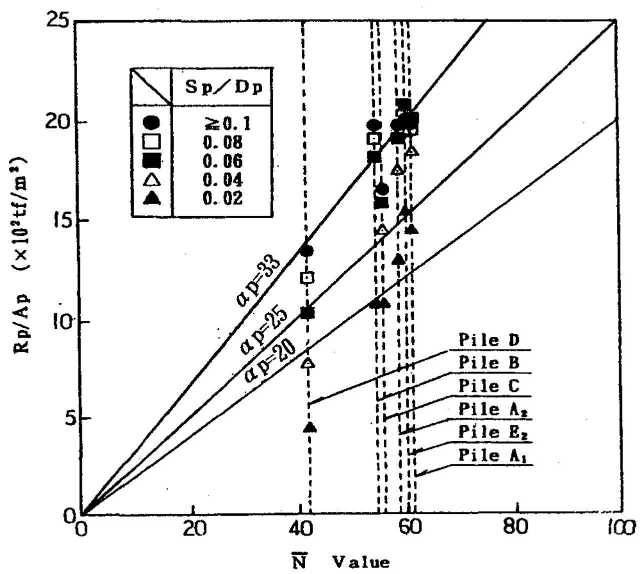


Fig.7 Relation between Rp/Ap and N

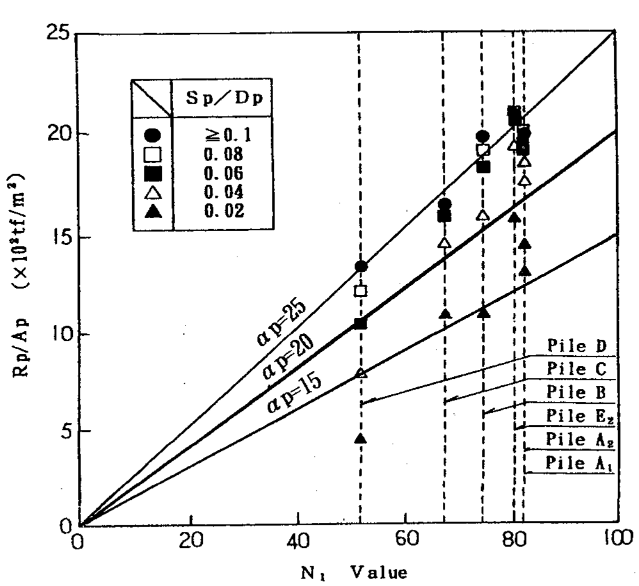


Fig.8 Relation Betweewn Rp/Ap and N_1

estimated by using data from loading test depends to a great extent on the way by which average N-value is determined. This suggests that it is of exterme importance to establish a method to verify that the tip of a bored pile be firmly placed in its load bearing layer so as to ensure that it attains an appropriate load bearing capacity as required.

CONCLUSIONS

In this study, possibility was examined to estimate, with a reasonable accuracy, the ultimate tip load of a long precast bored pile, by using data from a loading test not conducted to its full bearing capacity. Data from multi-cycle loading test were analyzed by assuming that they follow a Weibull distribution curve. Ultimate load at the tip of a pile, defined as that corresponding to a settlement/diameter ratio (Sp/Dp) of 10% at its tip, was estimated by using data taken at each of the load levels, from maximum bearing capacity downward, as applied during its loading test. Accuracy was evaluated of such ultimate load in terms of settlement/diameter ratio at pile tip by comparing it with the actual ultimate tip load as measured. In addition, applicability was assessed of an equation was calculated. Ultimate bearing capacity of bored pile by using two different types of average N-values. The results were compared with the corresponding load as estimated with the proposed method. The main conclusions from this study are as follows:

(1) The ultimate tip load as estimated by using data on load-settlement/diameter ratio and load-residual-settlement/diameter ratio taken at the top of a given pile is larger, and therefore is more likely to be on dangerous side, than that estimated by using such data taken at its tip. The difference can be attributed to the fact that load-residual-settlement characteristic of a pile at its tip is not directly related to the load-settlement characteristic at its top.

(2) To estimate, with an error no greater than 10%, the ultimate tip load of a bored pile, defined as that at which settlement at its tip attains 10% of its diameter, data are needed from a loading test that has been conducted at least to a load level at which its settlement/diameter ratio (Sp/Dp) reaches 0.075 at its tip.

(3) Eq.(4) can satisfactorily be applied to calculate the ultimate tip load of a broad pile by assuming α=25 and N=N1, provided that settlement/diameter ratio (Sp/Dp) at its tip is about 0.04, the result therefrom being substantially smaller than the ultimate tip load (Rp/Ap)u measured as corresponding to a settlement/diameter ratio of 10% at its

tip, and therefore can safely be used for pile foundation design practice.

(4) The ultimate tip load as calculated by substituting α=25 and N=N1 into Eq.(4) shows a good agreement with the corresponding load as determined by using test data taken at a settlement/diameter ratio (Sp/Dp) around 0.06. Moreover, Eq.(4) gives substantially smaller ultimate tip loads than those determined by using test data taken at a settlement/diameter ratio (0.04 at pile tip) for Eq.(4) when calculating the tip load of a pile bored by an authorized method.

It should be added that upon designing an actual pile foundation, due care must be taken to determine an appropriate extent or load level to which loading test should be carried out on a pile composing such foundation by conducting a previous analysis on its required bearing capacity. When applying the method herein proposed, or Eq.(4) herein examined, to a specific case, the engineer in charge needs exercise his/her judgment by making good use of his/her technical skills and knowledge to determine the details of the loading test to be conducted or the way the equation is to be applied by taking into account the particular conditions pertaining to each application varying in purpose, type as well as importance, as such method and equation are only intended for general use.

Pile foundation design, as currently practiced, is based on an allowable stress criterion. Trend has been on the rise, however, to design such foundation by using a load resistance factor or to adopt limit state design. When applying the limit state design method, different safety factors are applied depending on the types of uncertainty involved in a given design, to provide for all sort of unknown risks as has been the practice. Problems remain, however, how an upper limit should be defined of the load on a pile in terms of its settlement. To solve the problem, relationship needs to be identified between the limit load for the structure the foundation is to bear, of which such pile is a component, and its settlement which may vary from those of the other piles composing such foundation. In order to solve the problems, detailed data would be required of loading tests at every site, along with the quantitative technical information on bearing layer there. Such data and information would greatly improve pile foundation design practice, enabling us to work out a truly reliable bearing capacity.

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