# Bearing capacity of cast-in-place piles

## Capacité portante des pieux moulés dans le sol

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SYNOPSIS On the basis of one hundred and eleven in-situ load tests of cast-in-place piles, factors influencing bearing capacity were statistically analyzed. Among many factors, pile diameter and pile length were identified to be the most predominant. The comparison was made between measured and calculated bearing capacity over wide range of these two factors, and the applicability of a present bearing capacity formula of cast-in-place piles was clarified when they were used in engineering practice.

## INTRODUCTION

In determining bearing capacity of cast-in-place piles, all the design criteria authorized in Japan recommend in-situ load test rather than the direct use of bearing capacity calculation formula. In most cases of engineering practice, however, the prediction of the bearing capacity is made only in accordence with a calculation formula because of the limitation of both construction cost and construction period. In case of applying a calculation formula to design, however, high amount of uncertainty must be expected in the results of computation. In-situ and laboratory soil tests are, for instance, inevitably associated with certain amount of testing errors. Even in the design formula some errors are also expected because of theoretical assumptions for simplification of real soil behavior. The calibration of these errors should be made by the comparison of computed values with actually measured bearing capacity in in-situ load tests. However, a straight comparison between measured and computed bearing capacity of piles tends to show a large variance and does not always reveal good correlation. This is because there are many factors which influence bearing capacity of piles, such as pile diameter, pile length, N-values and soil quality of bearing stratum, penetration length of pile point bearing stratum, and so on. The comparison between measured and computed bearing capacity should, therefore, be characterized by those factors, and the applicability as well as the limitation of a design formula of bearing apacity of piles should also be described in terms of the ranges of those factors.

## FACTORS INFLUENCING THE BEARING CAPACITY OF CASE-IN-PLACE PILES

The samples for in-situ load test of cast-in-place piles used in this analysis were collected widely in great number for many years, and hundred and eleven cases with high reliability (85 cases with earth drill piles and 26 cases with Benoto piles) were selected from them. Although there exist various factors influencing the magnitude of bearing capacity of cast-in-place piles, in the present paper the following are studied: pile diameter D, pile length L, N-values at pile point, mean N-values $\overline{N}$ averaged over 5D length measured from 1D deep below pile point to 4D above the point, and penetrated length of the pile into bearing stratum L'; The effect of these factors are statistically analyzed through examining measured bearing capacity obtained from field load tests. The results are shown in Figs. 1-5, in which measured bearing capacities of earth drill piles are distinguished from those of Benoto piles. In these figures Rm denote measured bearing

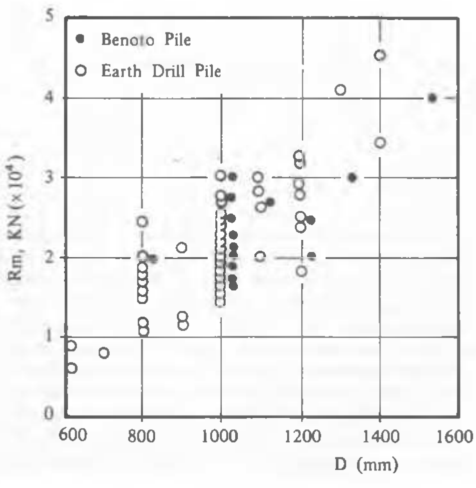



Fig.1 Relationship between Rm and D

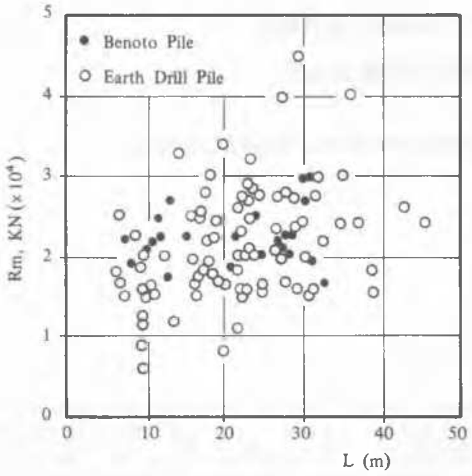



Fig.2 Relationship between Rm and L

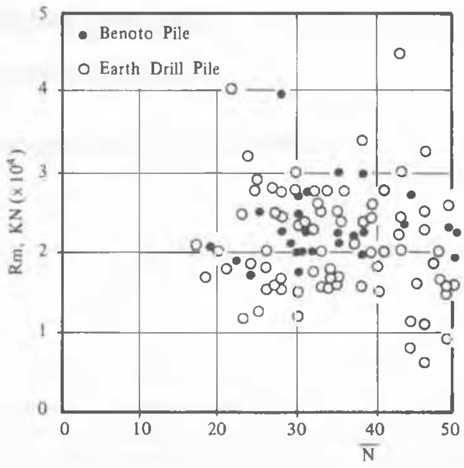



Fig.4 Relationship between Rm and $\overline{N}$

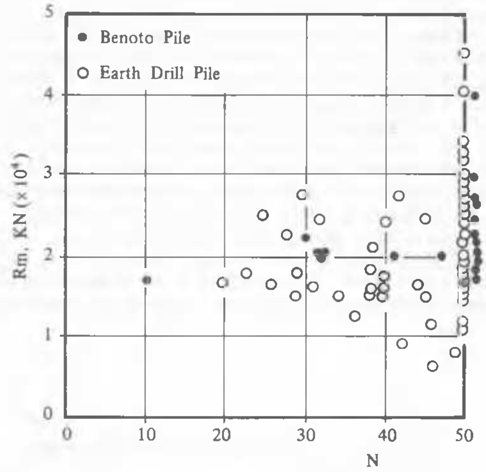



Fig.3 Relationship between Rm and N

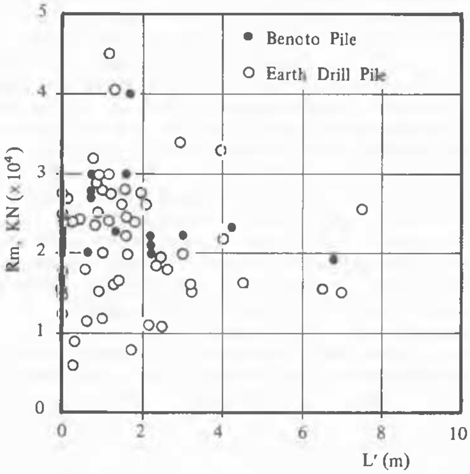



Fig.5 Relationship between Rm and L'

Capacity, the definition of which follows either Rm = 1/2 Qy or Rm = 1/3 Qu where Qy and Qu are yield load and ultimate load, respectively, Since it was very few to observe ultimate load Qu in field test, all the Rm's in these figures followed the former definition except two cases. These figures show a high correlation between the Rm and the pile diameter D, but the other factors L, N, $\overline{N}$ and L' are difficult to find a good correlation with bearing capacity Rm. Furthermore, followings are drawn from Figs. 1-5: (i) the considerably narrow rang of bearing capacity can be found for each pile diameter, and (ii) there is no significant difference in bearing capacity between earth drill piles and Benoto piles.

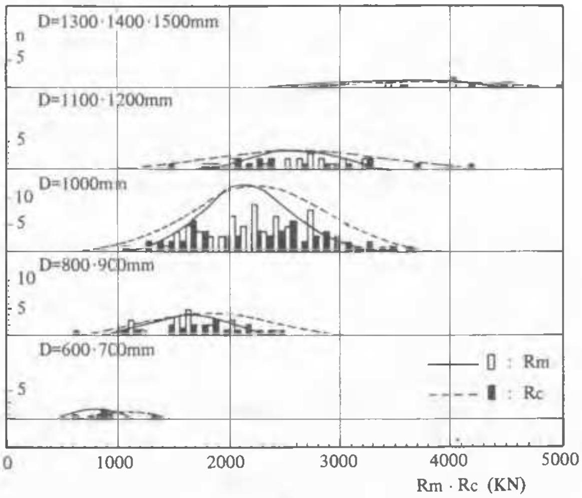
## A DESIGN FORMULA OF CAST-IN-PLACE PILES NOW IN USE IN JAPAN

The applicability of the design formula for cast-in-place piles recommended by Architectural Institute of Japan is examined there through the comparison with insitu measurement. The calculation of the bearing capacity of cast-in-place piles is made by the following equation (the AIJ, Design Criteria for Calculating the Foundation Construction, 1976):

$$Rc = \frac{1}{3}\left\{15\bar{N}Ap + \left(\frac{NsLs}{5} + 2NcLc\right)\right\}\psi - W \quad ...(1)$$

Where Rc: Allowable bearing capacity for long age loading (kN)
- $\bar{N}$ : The mean N-values given in the former section, which should not exceed 50
- Ap: Total section area of pile point ($m^2$)
- Ns: A mean N-value measured in a sandy stratum whithin a ground, which also should not exceed 50
- Ls: Pile length penetrated into the sandy stratum
- Nc: A mean N-value obtained in a clayey stratum within a ground, which should take the value between 0.5 ∿ 4
- Lc: Pile length penetrated into the clayey stratum (m)
- $\psi$ : Pile perimeter (m), and
- W : Dead load of cast-in-place concrete pile (kN)

Fig.6 shows the correlation between measured bearing capacity Rm and calculated capacity Rc, in which the distribution is also made between earth drill piles and Benoto piles. Although a large scatter is seen in this figure, it is possible to find a positive correlation between Rm and Rc, which may be why Eq. (1) is employed widely in engineering problems. However, in order to get better performance than Fig. 6 implies, the comparison between Rm and Rc should be made more in details considering the effects of some factors such as pile diameter D and pile length L which have been observed to be influential on a measured bearing capacity. Fig. 7 shows the frequency distribution of Rm and Rc at each pile diameter. The pile diameters were classified into five groups: 600 ∿ 700mm, 800 ∿ 900mm, 1000mm, 1100 ∿ 1200mm, and 1300 ∿ 1500mm. In this figure the frequency n, the mean value $\mu$, the standard deviation S and the coeffecent of variation V of both Rm and Rc are also tabulated for each class of pile diameter. From this figure and the table, it can be seen that the distribution of Rc lies leftward compared with the distribution of Rm when pile diameter D is less than 1000mm, and vice versa when D > 1000mm. In other words, Eq. (1) tends to give the prediction of bearing capacity on a safe side when D ≦ 1000mm while on a risky side when D > 1000mm. This tendency can be seen more clearly taking the influence of pile length on a bearing capacity into consideration.




| D (mm) | n | Rm | | | Rc | | |
|---|---|---|---|---|---|---|---|
| | | $\mu$ | S | V | $\mu$ | S | V |
| 600 ~ 700 | 3 | 77 | 12 | 0.156 | 99 | 22 | 0.222 |
| 800 ~ 900 | 21 | 163 | 35 | 0.215 | 185 | 58 | 0.314 |
| 1000 | 64 | 216 | 40 | 0.185 | 227 | 62 | 0.273 |
| 1100 ~ 1200 | 18 | 264 | 39 | 0.148 | 259 | 71 | 0.274 |
| 1300 ~ 1500 | 5 | 379 | 53 | 0.140 | 391 | 84 | 0.214 |

Fig. 7 Distribution of Rm and Rc for Each Pile Diameter D

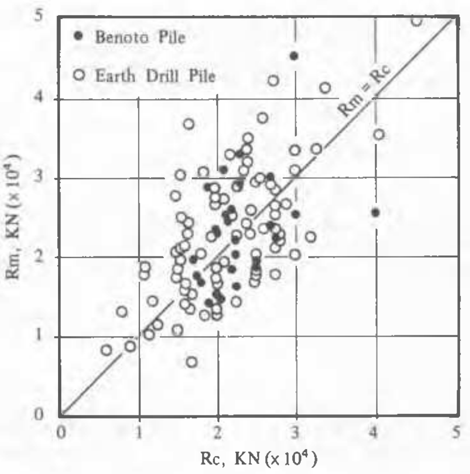
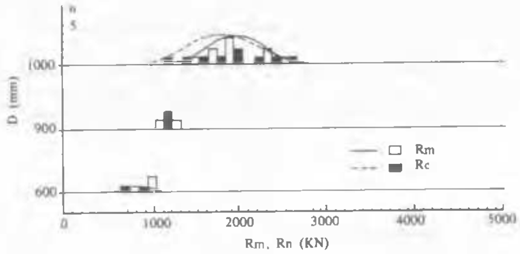


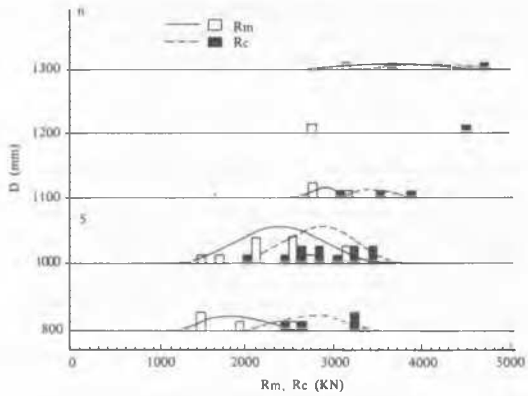

Fig.6 Relationship between Rm and Rc

In the following analysis the pile lengths are classified into four groups: less than 10m, 10 ∿ 20m, 20 ∿ 30m, and more than 30m. Shown in Figs. 8 (a)-(d) is the comparison between Rm and Rc made in each group. From these figures it should be noted that the threshold pile diameter which was found to be 1000mm based on Fig. 7 will be dependent of pile length. Figs. 8 (a) and (b) show that if pile length is less than 20m Rc tends to be smaller than Rm even when pile diameter D is greater than 1000mm as far as D is less than 1200mm. On the other hand, if pile length is greater than 20m Rc tends to become larger than Rm as far as pile diameter D is greater than 800mm. Thus, it has been found that there exist two kinds of threshold values, one is D ≈ 800 ∿ 1200mm and the other is L = 20 m. The bearing capacity computation formula Eq. (1) tends to give "under estimates" (i.e. the prediction on a safe side) below these threashold values, and vice varsa above the thresholds.



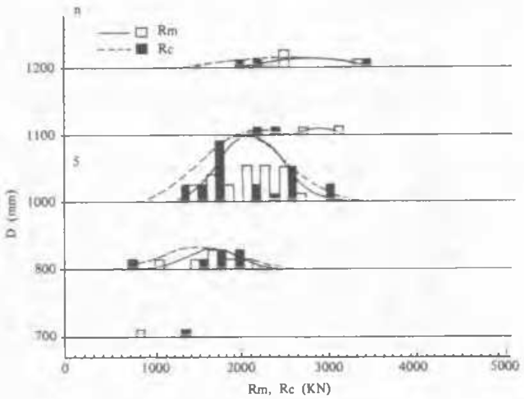

| D (mm) | n | Rm | | | Rc | | |
|---|---|---|---|---|---|---|---|
| | | μ | S | V | μ | S | V |
| 600 | 2 | 75 | 15 | 0.200 | 84 | 2 | 0.024 |
| 900 | 2 | 120 | 5 | 0.042 | 107 | 6 | 0.056 |
| 1000 | 9 | 192 | 32 | 0.167 | 175 | 42 | 0.240 |

(a) L < 10m



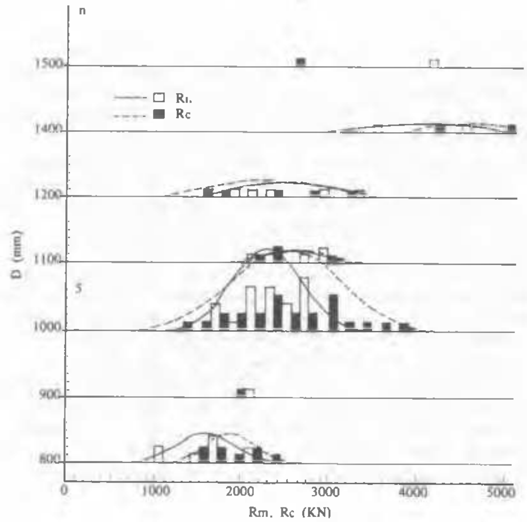

| D (mm) | n | Rm | | | Rc | | |
|---|---|---|---|---|---|---|---|
| | | μ | S | V | μ | S | V |
| 800 | 6 | 163 | 25 | 0.153 | 152 | 41 | 0.270 |
| 1000 | 20 | 209 | 35 | 0.167 | 198 | 49 | 0.247 |
| 1100 | 2 | 285 | 15 | 0.053 | 219 | 17 | 0.078 |
| 1200 | 3 | 276 | 37 | 0.134 | 242 | 65 | 0.269 |

(b) 10m ≦ L < 20m




| D (mm) | n | Rm | | | Rc | | |
|---|---|---|---|---|---|---|---|
| | | μ | S | V | μ | S | V |
| 800 | 8 | 157 | 32 | 0.204 | 186 | 28 | 0.151 |
| 1000 | 24 | 225 | 38 | 0.169 | 246 | 60 | 0.244 |
| 1100 | 4 | 255 | 33 | 0.129 | 241 | 26 | 0.108 |
| 1200 | 5 | 246 | 52 | 0.211 | 222 | 59 | 0.266 |
| 1400 | 2 | 395 | 55 | 0.139 | 454 | 43 | 0.095 |

(c) 20m ≦ L < 30m




| D (mm) | n | Rm | | | Rc | | |
|---|---|---|---|---|---|---|---|
| | | μ | S | V | μ | S | V |
| 800 | 4 | 185 | 36 | 0.195 | 263 | 34 | 0.129 |
| 1000 | 11 | 231 | 47 | 0.203 | 277 | 41 | 0.148 |
| 1100 | 3 | 277 | 17 | 0.061 | 335 | 30 | 0.090 |
| 1300 | 2 | 353 | 53 | 0.150 | 399 | 48 | 0.120 |

(d) L ≧ 30m

Fig.8 Distribution of Rm and Rc for Each Pile Length L

## CONCLUSION

Through examining case records of in-situ measurements of bearing capacity of cast-in-place piles and analysing those data by the design formula widely used in Japan, followings are considered to be drawn:

1) Pile diameter D and pile length L and the most predominat factors which influence the in-situ bearing capacity of caşt-in-place piles.
2) D = 800 ∿ 1200mm and/or L = 20m will be a threshold value when prediction is made on in-situ value by using the bearing capacity calculation formula, that is, the formula gives under or over estimates around these threshold values.

## REFERENCE

AIJ (1976): Design criteria for calculating the foundation construction.