Fundamental Study on End Resistance of Bored Precast Pile

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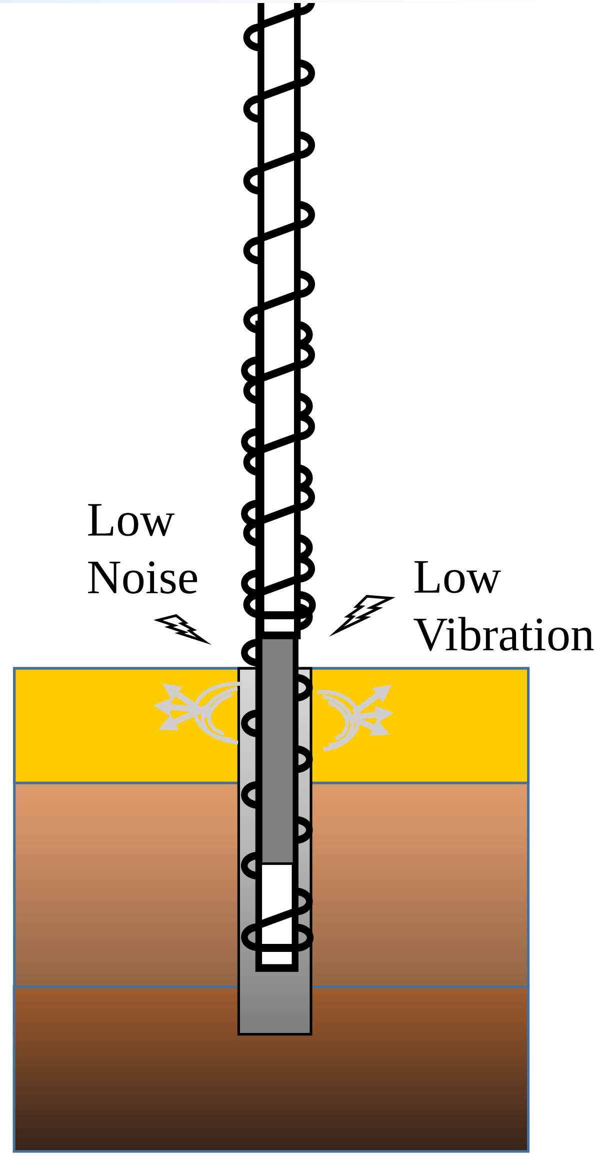
INTRODUCTION

- In Japan, many buildings were constructed using the driven pile construction method in 1950-1965. However, the loud noise and large vibration generated from machines were a serious problems in the big city.

- And the Noise Regulation Act came into effect in 1968. Since then, the driven pile construction method has been prohibited in urban area of Japan.

- Therefore, the cast-in-place pile construction method and the bored precast pile construction method were developed. These methods were progressed very much, and various methods have been developing.



Bored precast pile construction method

INTRODUCTION

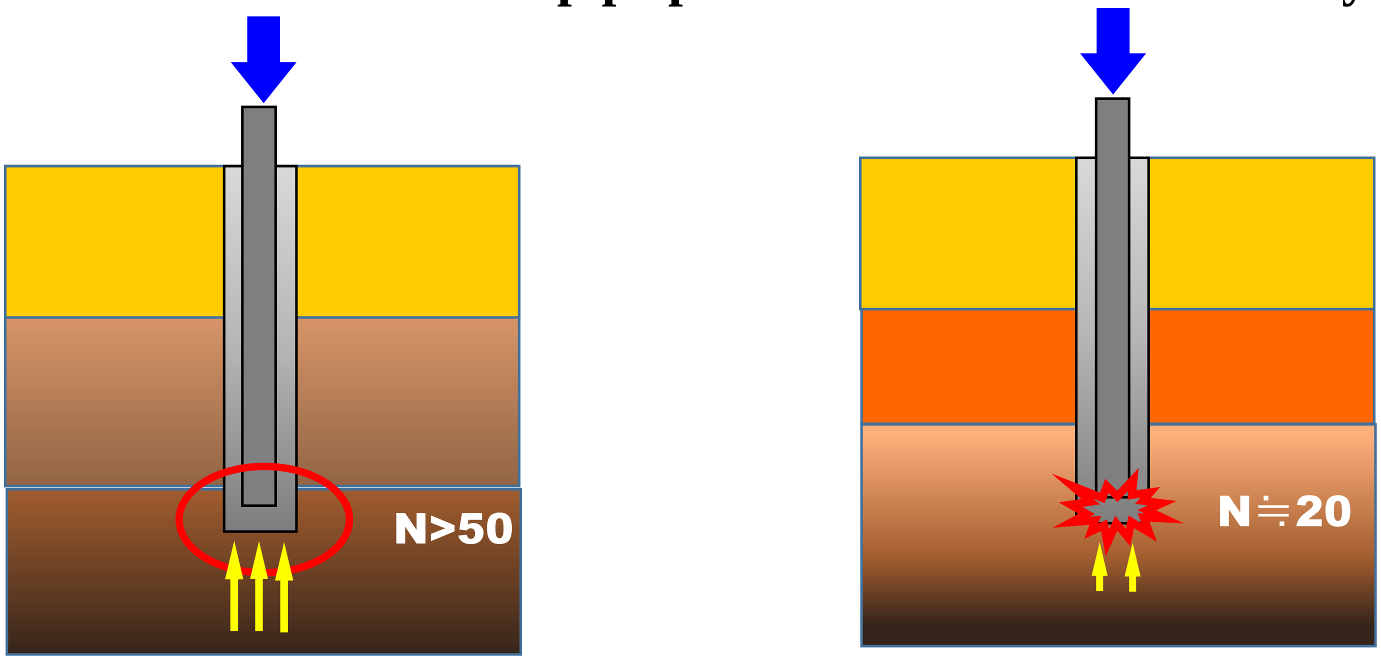
- **Recently, small sized piles also apply to the bored precast pile construction method for small buildings such as detached residences or retaining walls. And in this method, quality control of the root part is very important.**

- **When the strong root can be built, the pile end area contributing to the resistance increase and large end bearing capacity will be performed. But if not, the pile end resistance will be lack and the upper structure may be subject to terrible damage.**

Retaining wall with small steel pile constructed by pre-bored method

INTRODUCTION

- It is necessary to build a homogeneous and a strong root solidifying part in the pile end zone.
- If the pile end is fixed in a hard layer, it is relatively easy to build the root hardening part with good quality.
- However, in the case of a soft cohesive layer, or much water is flowing, the strength of the root part can be short.
- And small-diameter steel pipe piles are often fixed in such layers.



Sandy Soil or Gravel

Cohesive Soil or Much Water is flowing

INTRODUCTION

The objective of this study:

➡ To make clear the characters of the end resistance for the bored precast pile with the weak root part.

VERTICAL LOADING TEST (small sized model test)

- We performed static axial compressive loading test.
- The pile tip is covered with plaster.
- The model piles set up with simulating actual stress condition of the pre-bored method.

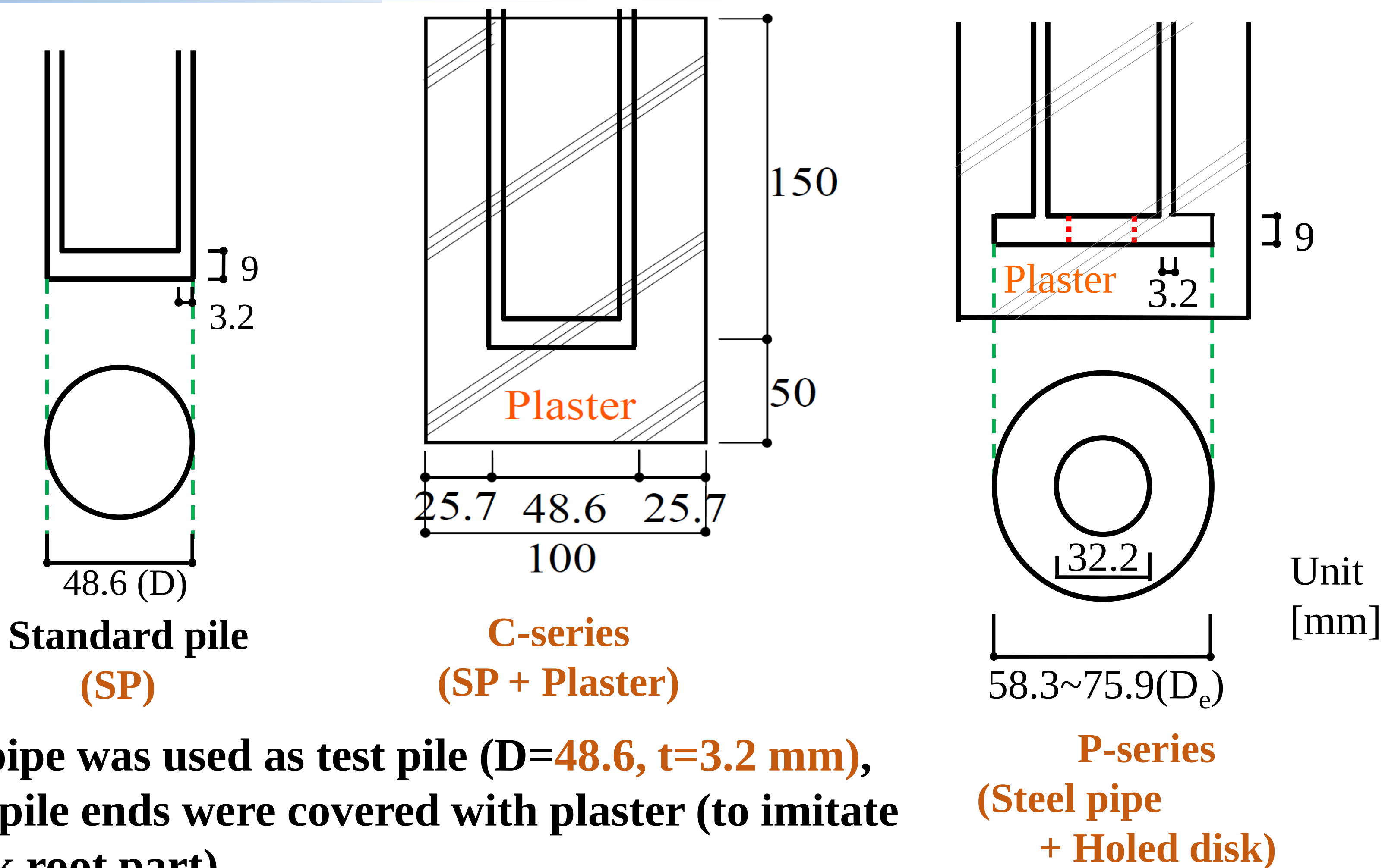
⬇

SIMPLIFIED CALCULATION METHOD

- We discuss the test results. (End resistance, Destruction pattern, etc.)
- We propose a simplified calculation method.
- It can estimate the end resistance of bored pile in consideration of the root part destruction.

VERTICAL LOADING TEST

Test Piles and Test Series



- A steel pipe was used as test pile (D=**48.6, t=3.2 mm**), and the pile ends were covered with plaster (to imitate the weak root part).
- SP pile : Standard pile (Not covered with plaster)
- C-series : Standard pile covered with plaster
- P-series : Steel pipe + Holed disk (De=58.3~75.9 mm) and covered with plaster

VERTICAL LOADING TEST

Test Piles and Test Series

Table 1 Test pile Factors

Series	Symbol	Water-Plaster Ratio *W/P* (%)	External diameter of pile end D_e (mm)	Pile end diameter *D* (mm)
-	SP(Standard)	-	48.6	48.6
C-series	C-60	60		100
	C-80	80		
	C-100	100		
	C-120	120		
P-series	P-58	120	58.3	100
	P-68		67.6	
	P-75		75.9	

- The C-series (C-60 to C-120) : To investigate influence of the root strength.

Plaster: W/P (Water-plaster ratio)=60% to 120%.

- The P-series (P-58, P-68, P-75) : To discuss the effect of end disk plate.

W/P of the P-series is 120% (very weak).

VERTICAL LOADING TEST Model Ground Preparation

- **A steel circular test tank is used.**
  Diameter is 1000 mm.
  Depth is 1000 mm.
- **No. 5 silica sand in dry condition is used for the model ground.**
- **The test ground is prepared by the air pluviation technique with double nets for dispersion.**
- **The N-values of the pile end is N=2 or N=3.**

Table 2 Model ground characteristics

Density (ρ)	1760 kg/m^3
Void ratio (e)	0.512
Relative density (D_r)	87.50 %
Internal friction angle (φ)	45°

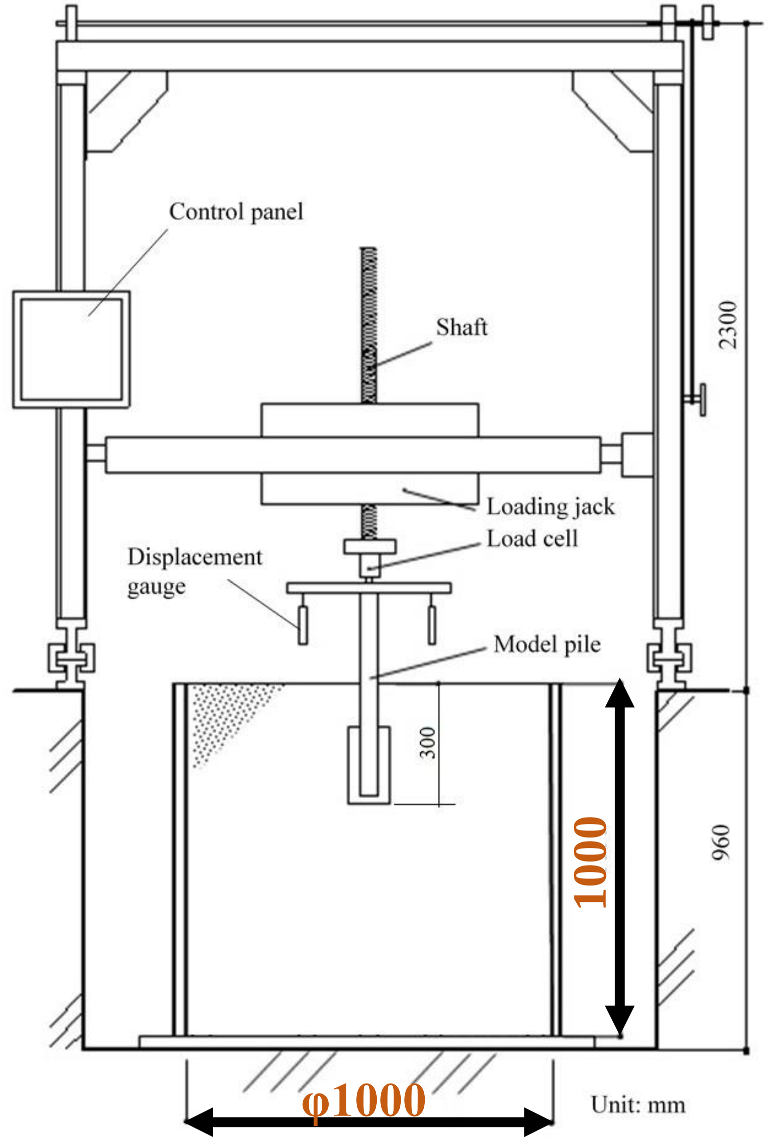
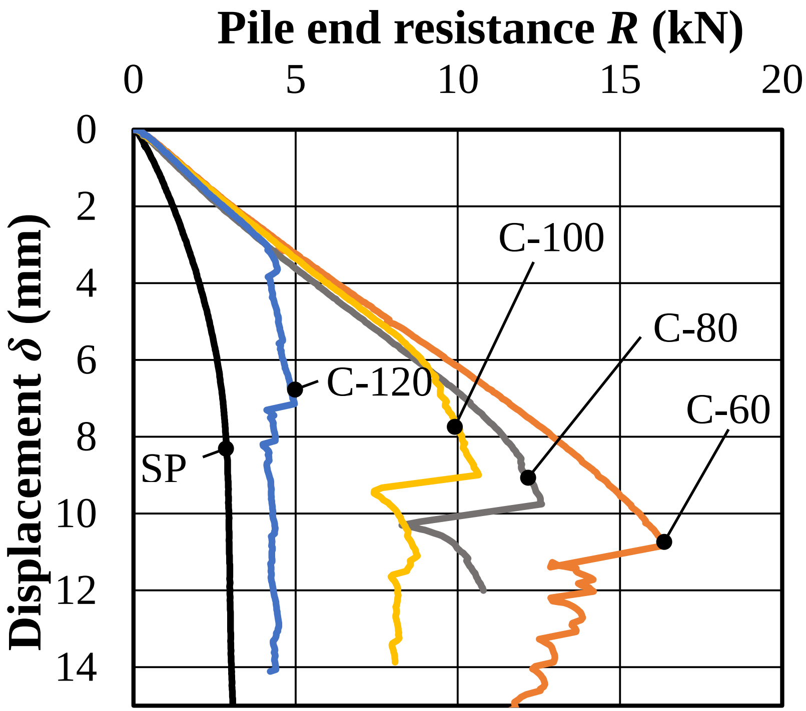


Fig. 4 Experimental apparatus

RESULTS OF LABORATORY EXPERIMENT

Test results of C-series



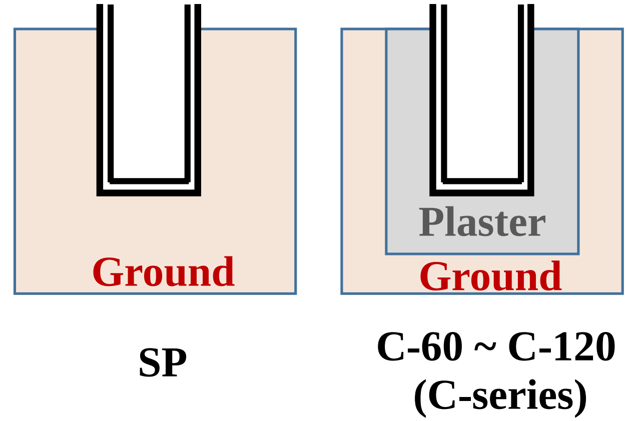


Fig. 5 Relationship between displacement and pile end resistance (C-series)

- **The test piles with root part(fromC-60 to C-120) show larger pile end resistances(*R*) than that of the standard pile (SP) because of enlarged-diameter effect.**
- **C-series show almost the same resistance values until 3.5 mm of displacement.**
- **However, after that, the increase rates of the resistance are reduced, and the resistance values decrease suddenly.**

RESULTS OF LABORATORY EXPERIMENT

Test results of C-series

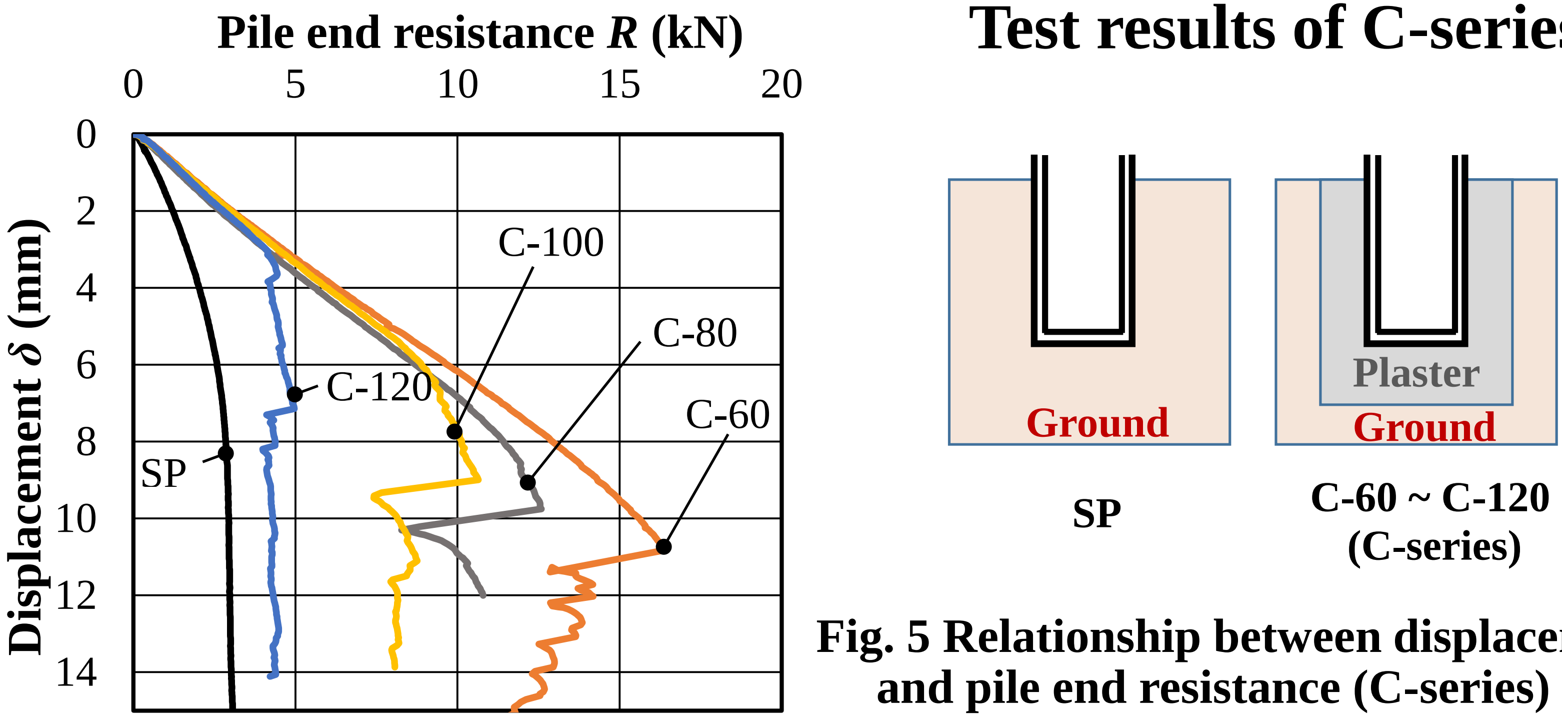


Fig. 5 Relationship between displacement and pile end resistance (C-series)

- **Then, it is surmised that the destruction of the root hardening part has arisen.**
- **The magnitude order of the maximum resistance(*R*) is the smaller the water-plaster ratio, the larger the maximum resistance.**

RESULTS OF LABORATORY EXPERIMENT

Test results of C-series

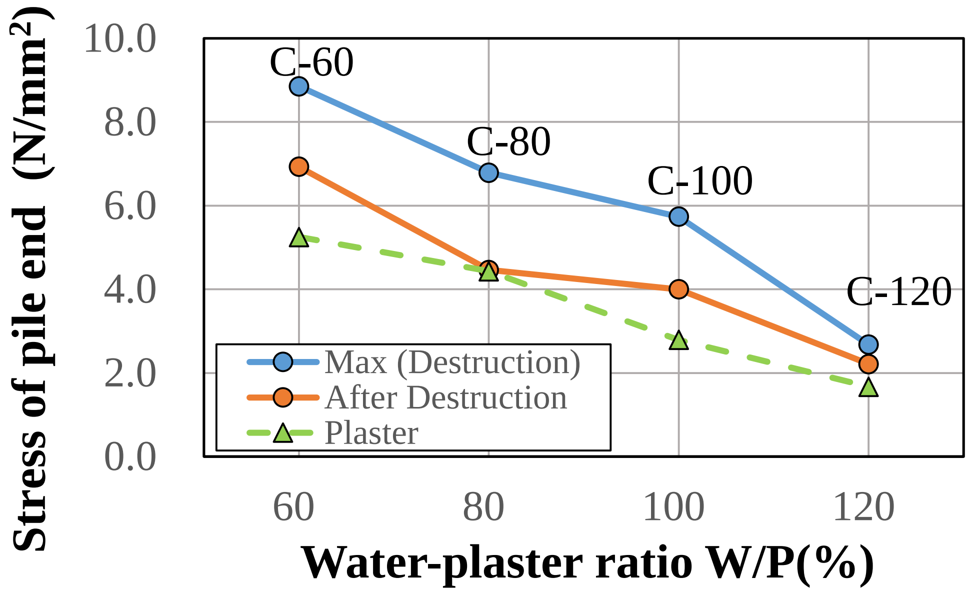
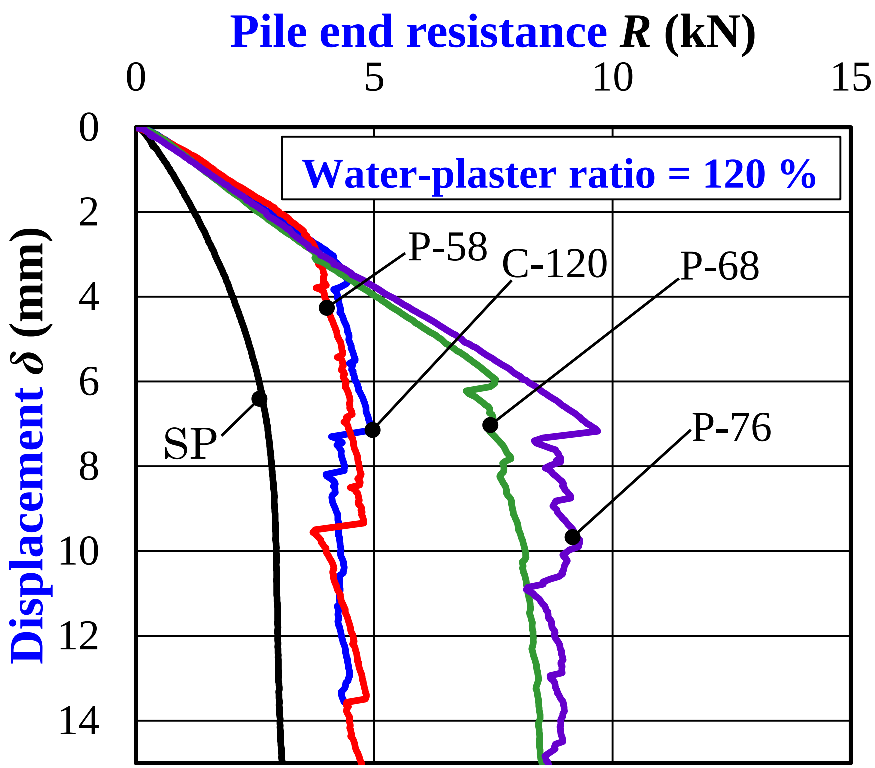


Fig. 7 Relationship between water-plaster ratio and destruction stress of pile end (C-series)

- **The stress is the quotient of the end resistance divided by the pile tip area, and plaster compressive strength is added to the figure.**
- **The pile end stresses at the destruction (maximum values) are approximately 1.5 times large as the compressive strengths of the plaster.**
- **Even after the destruction, the pile end stresses do not show the smaller values than the plaster's strengths. This phenomenon is presumed to be due to side reaction stress around the pile tip.**

RESULTS OF LABORATORY EXPERIMENT



Test results of P-series

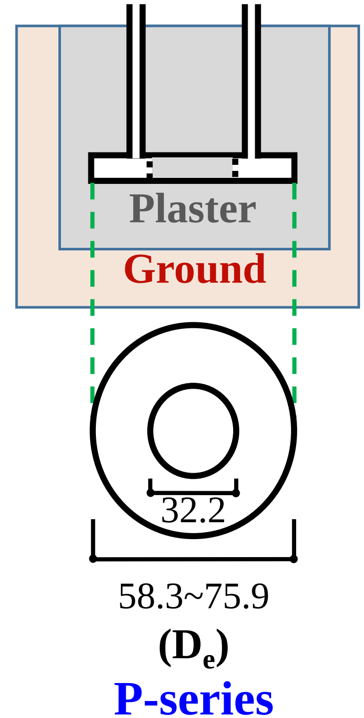
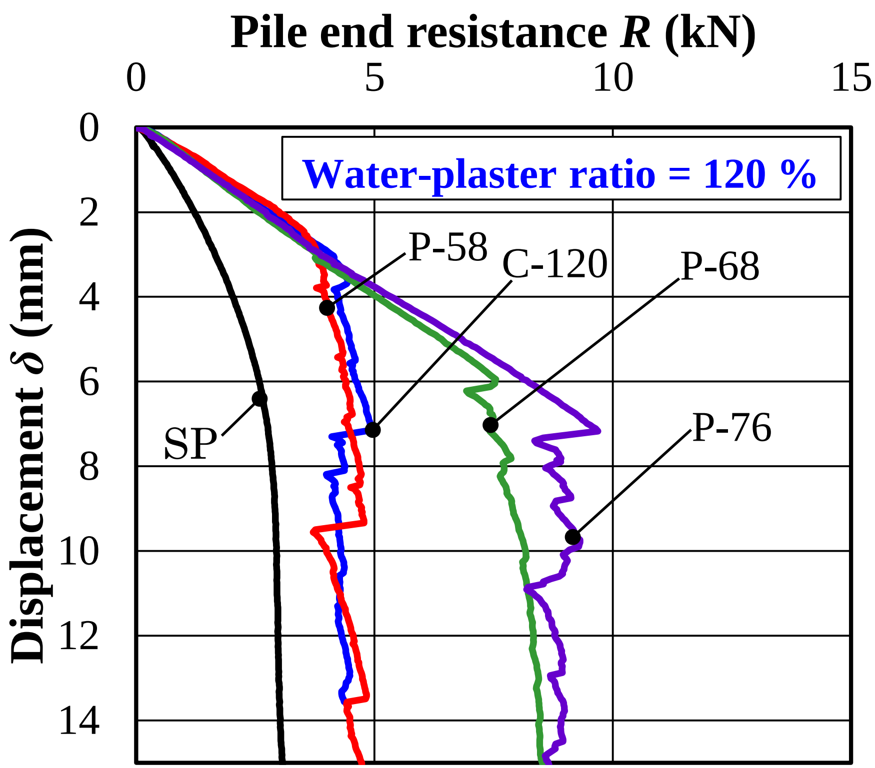


Fig. 6 Relationship between displacement and pile end resistance (P-series)

- In the P-series, the R value of P-58 (the diameter of the end disk is De =58.3 mm) is as the almost same as the C-120's.

- However, the R values of P-68 and P-76 (De = 67.6 mm and 75.9 mm) are larger than that of the C-120's, and the larger the diameter, the larger the pile end resistance.

RESULTS OF LABORATORY EXPERIMENT



Test results of P-series

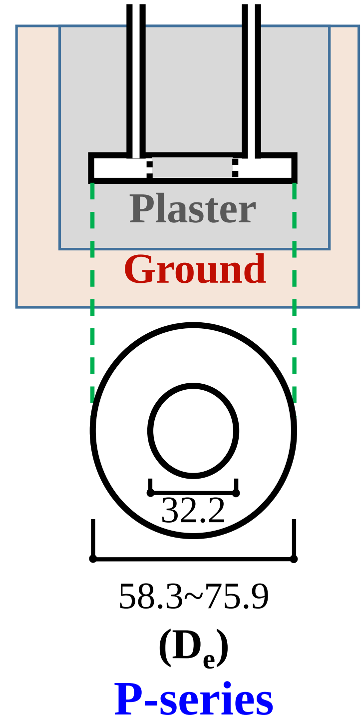


Fig. 6 Relationship between displacement and pile end resistance (P-series)

- Furthermore, similar to the C-series, the tip resistance has decreased after the maximum load, but the rate of decrease is relatively small.

RESULTS OF LABORATORY EXPERIMENT

Test results of P-series

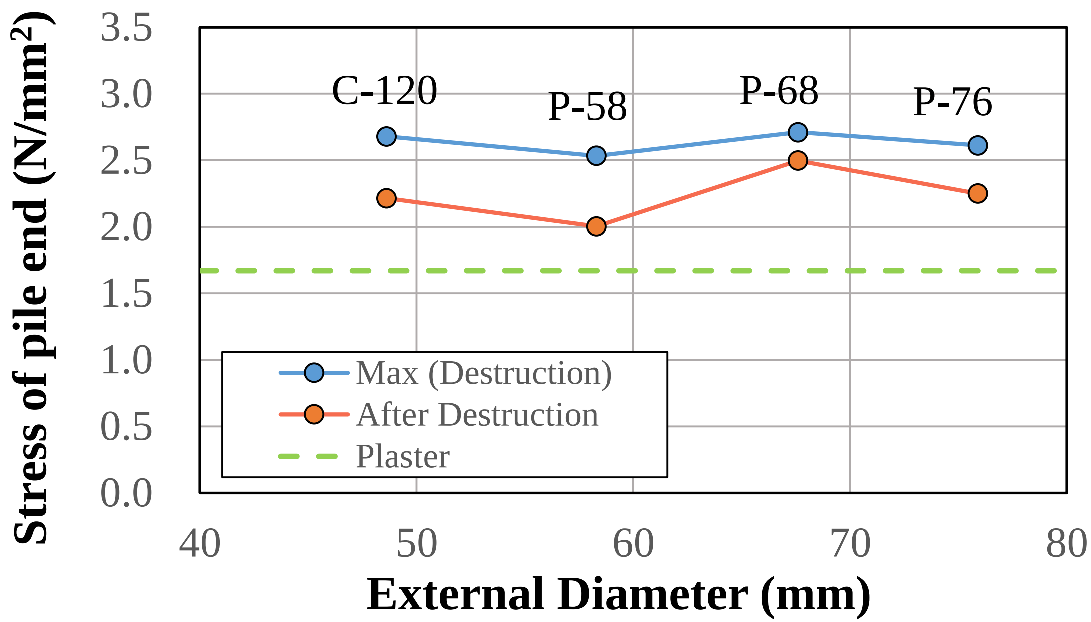
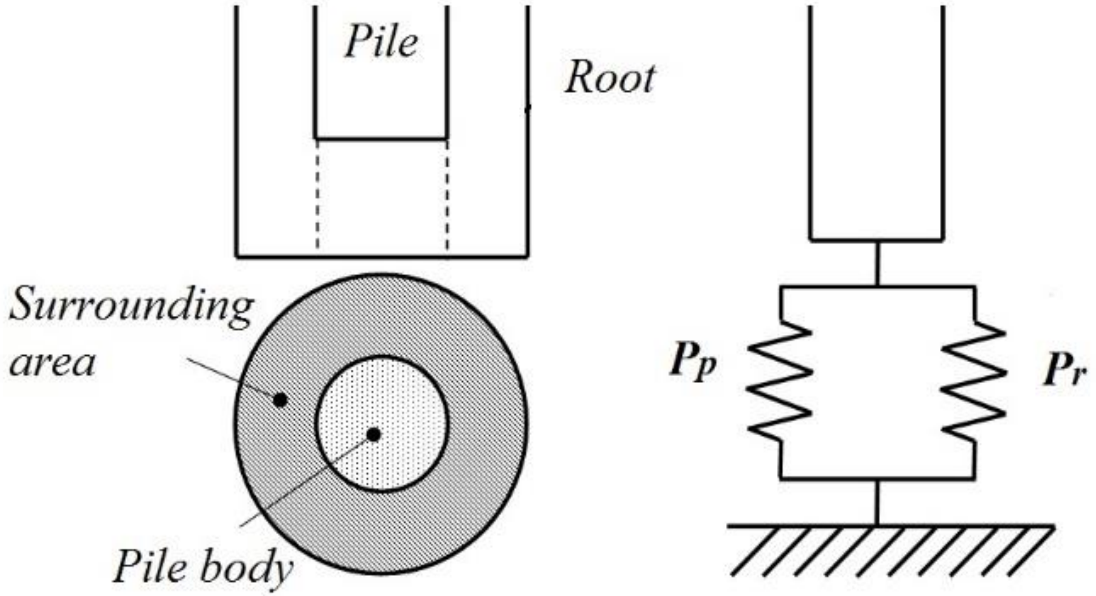


Fig. 8 Relationship between external diameter of the end plate and destruction stress of pile end (P-series)

- **The pile end stresses of P-series at the root breakage are almost the same value of 2.5 N/mm^2, and is also same as that of C-120's.**
- **The end resistance of a pile with the end disk plate does not decrease greatly even after the root breakage because the pile end has a large effective area.**
- **The pile with the end disk plate will exhibit sufficient end resistance even if the stiffness of the root hardening part would be insufficient.**

SIMPLIFIED CALCULATION METHOD

Calculation model



$$R = P_p + P_r$$

Fig. 10 Calculation Model

- **We propose a simple calculation model as shown in fig.10.**
- **This model assumes two nonlinear springs, one spring handles the resistance of the pile body (*P_p*), and another spring responds for the resistance of surrounding the body (*P_r*).**
- **The pile end resistance (*R*) is given as the sum of these.**

SIMPLIFIED CALCULATION METHOD

Relationship between pile end stress and displacement

- The stress of pile end (q) and displacement (y) are defined by the reference displacement (0.1D) and the stress of q_{max}, which is the stress at the reference displacement (0.1D).

$$q_{max} = \alpha N_t$$

- Where α is the bearing capacity factor and N_t is the N-value at pile end.
- Then, a trilinear skeleton curve is assumed as shown in fig. 11.

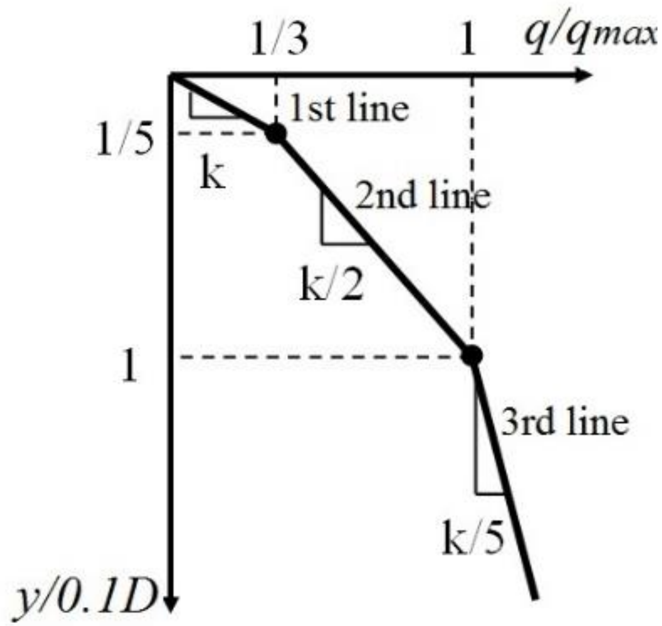


Fig. 11 Pile end resistance (R-y curve)

1st line $\dfrac{q}{q_{max}} = \dfrac{y}{6D}$ $\quad \left(\frac{y}{D} < 0.02\right)$

2nd line $\dfrac{q}{q_{max}} = \dfrac{y}{12D} + \dfrac{1}{6}$ $\quad \left(0.02 \le \frac{y}{D} < 0.1\right)$

3rd line $\dfrac{q}{q_{max}} = \dfrac{y}{30D} + \dfrac{2}{3}$ $\quad \left(0.1 \le \frac{y}{D}\right)$

SIMPLIFIED CALCULATION METHOD

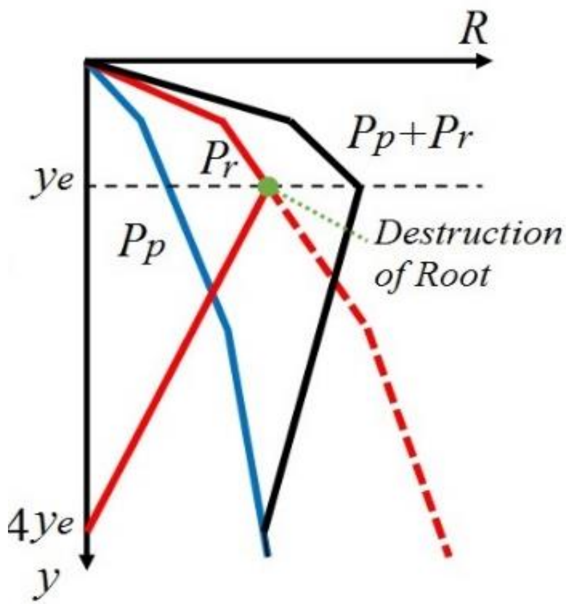


Fig. 11 Pile end resistance (R-y curve)

Pile end resistans force

- The resistance force P_p and P_r are calculated as follows;

$$P_p=\alpha N_t A_p \qquad P_r=\alpha N_t A_r$$

- A_p and A_r are the areas of the body portion and the surrounding portion, respectively.
- Moreover, as shown in fig. 11, it is assumed that the surrounding spring force P_r gradually decreases until 4 times of the displacement of y_e (y_e: breakage displacement) after the root break.
- In above manner, the relationship between pile end resistance force and displacement, i.e. P_p-y curve and P_r-y curve are determined.

SIMPLIFIED CALCULATION METHOD

Comparison between laboratory test and calculation results(C-series)

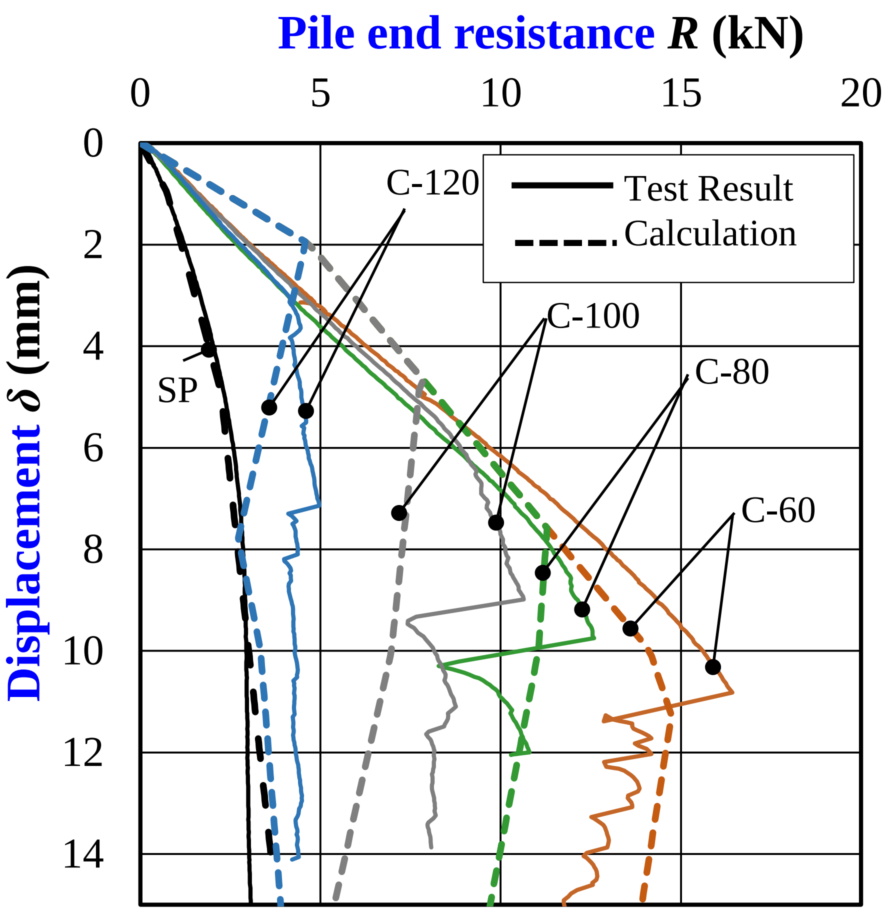


Fig. 12 Comparison between test and calculation results (C-series)

- **The calculated value of the SP-pile is in good agreement with the experimental result.**
- **This result shows that the characteristics of the Pile body spring (P_p-y curve) are suitable.**
- **In the C-series, the root destruction load of the calculation and test results shows approximately same value.**
- **However, at the phase of the load increasing, the calculation values are larger than the test results.**
- **It is presumed that this phenomenon is caused by lack of the stiffness of the root part, and some improvements of the P_r-y curve will be required.**

SIMPLIFIED CALCULATION METHOD

Comparison between laboratory test and calculation results(P-series)

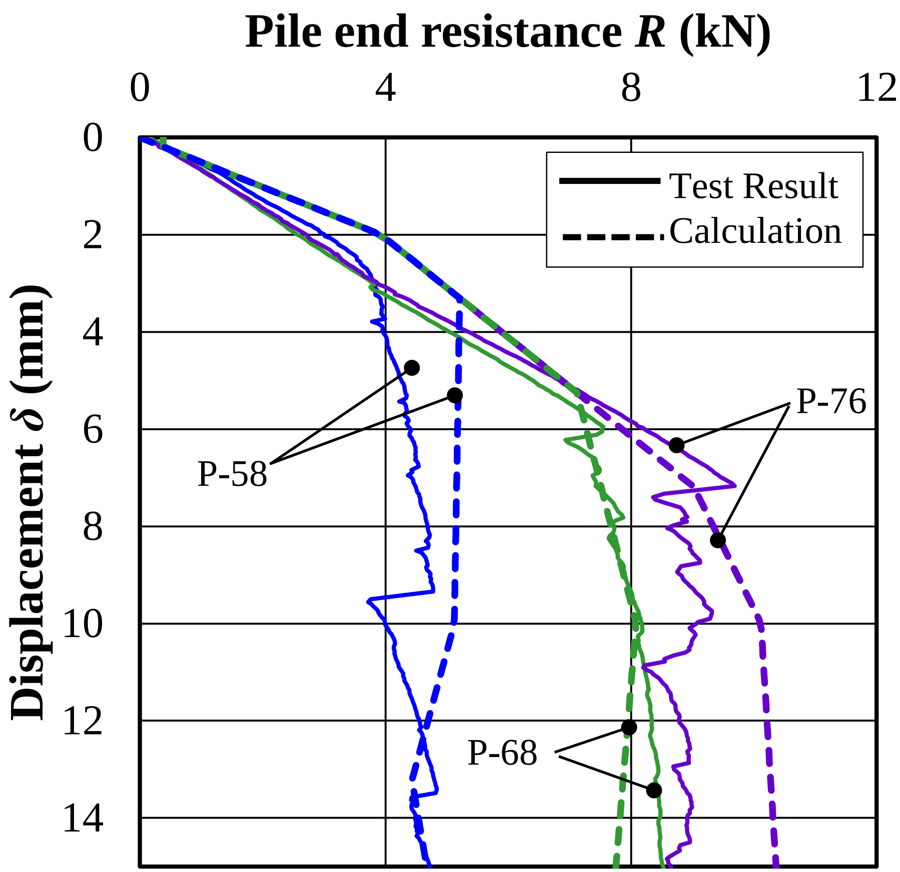


Fig. 13 Comparison between test and calculation results (P-series)

- **In the P-series although the calculation values are larger than the test results at the load increasing stage.**

- **The calculation results are well simulating the destruction of the root and subsequent transition of the resistance.**

- **This calculation method can be applied to a safer pile design because it can estimate the relationship between pile tip resistance and displacement considering the destruction of the root part.**

SIMPLIFIED CALCULATION METHOD

Comparison between laboratory test and calculation results(P-series)

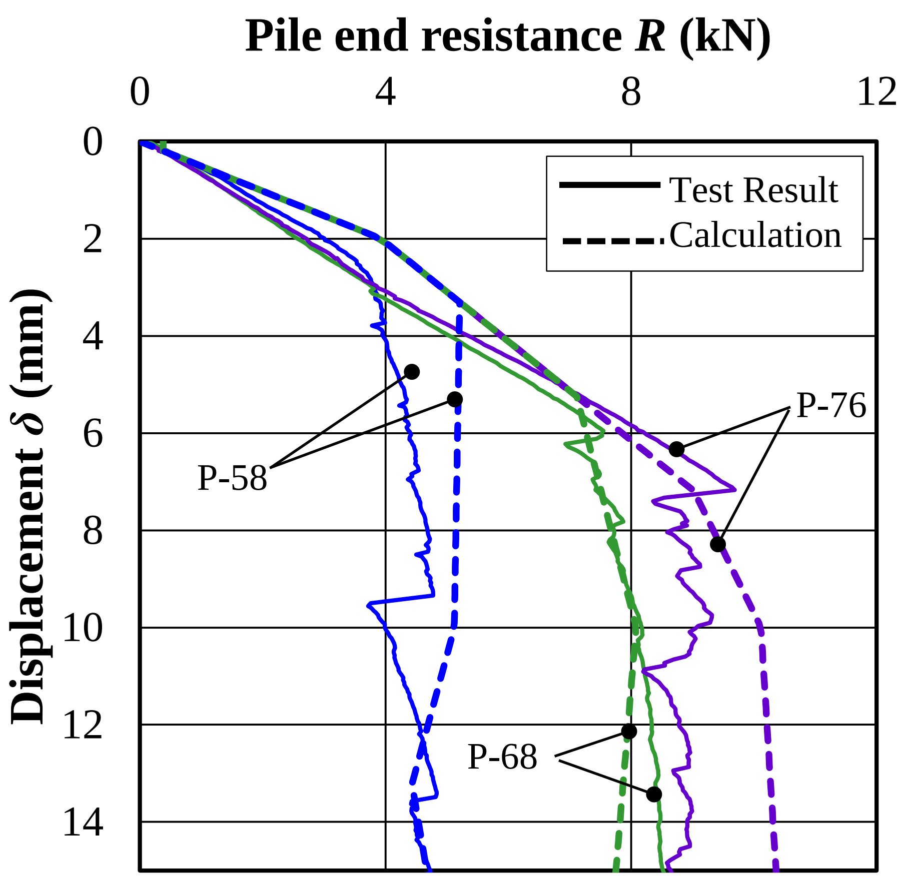


Fig. 13 Comparison between test and calculation results (P-series)

- **However, when applying this method to an actual pile, it is necessary to determine the bearing capacity factor (α) and the destruction strength of the root taking into consideration the characteristics of the supporting layer and the scale effect.**

CONCLUSION

- The pile end resistance of the bored pile is affected by the strength of the root part, and when the root part breaks, the resistance decreases suddenly.

- The pile which has a large disk plate into the tip, does not suffer a large load reduction even if the root is destroyed.

- The simplified calculation method was proposed which can consider the behavior of the destruction of the root part.

- In this method, the load-displacement relationship can be estimated from only the N-value and the bearing capacity factor.

- The calculation method was comparatively in good agreement with the laboratory experiment results by applying the appropriate destruction stress of the root.

Thank you very much for your kind attention

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