Consideration for End Shape of a Pile for Prebored Pile Construction Method

Sena MIYAZAKI
Graduate Student, College of Science & Technology, Nihon University, Funabashi, Chiba, Japan
Hideto SATO
Department of Architecture & Life Design, Nihon University Junior College, Funabashi, Chiba, Japan
Katsuhiro KANUKA
Kanuka Design Co., Ltd, Nishi-ward, Yokohama, Kanagawa, Japan
Yuuki HARIGAYA
Noix Co., Ltd, Aoi-ward, Shizuoka, Shizuoka, Japan

ABSTRACT

In the cement milk pile construction method, precast concrete pile or steel pipe pile is used, and the pile ends have a circular opening. In this paper, we described laboratory experiments for a static axial compressive load test of single pile. The objective of the tests is to make clear the characteristics of the vertical end bearing capacity of the pile with an opening in the pile tip. We discuss the relationship of the bearing capacity with the tip shape, and propose a more suitable shape of the pile end for the cement milk method. Subsequently, we try to confirm the validity of the improved pile tip by actual size load experiments.

KEY WORDS: Pile; prebored construction method; end bearing capacity; laboratory load test; actual size load test.

INTRODUCTION

The cement milk pile construction method is classified as part of the prebored pile construction method. Recently, the application number of this method has increased in urban areas of Japan because of the low construction noise and vibration. In this method, precast concrete hollow piles or steel pipe piles are used. Therefore, it is necessary to fill the piles with cement milk. If those pile ends are fixed in hard sandy soil or a gravel layer with good quality cement milk, they will show enough vertical bearing capacities. However, in soft or medium cohesive soil, vertical resistance might decrease because of insufficient stiffness of the cement milk. Accordingly, the cement milk strength is often ignored in the design of the end bearing capacity.

Goto and Katsumi (1967) pointed out that the blockade effect at the pile tip might not be demonstrated in a large diameter bored pile. In addition, Katsumi and Kitani (1982) indicated that the end bearing capacity of an open end pile cannot evaluate the same capacity as a closed end pile since the capacity depends on a sectional area of the pile end.

On the other hand, in the driving pile construction method, the end bearing capacity improves when the pile is driven into a deep embedment since the blockade effect is promoted (Komada et al., 1973 and Shimazaki et al., 1977). Furthermore, Yamahara (1973) reported that to make the diameter smaller or to attach divider plates inside the pile tip are effective in order to obtain large end bearing capacities.

The objective of this study is to develop the effective end shape of a pile for vertical bearing capacity, which can work even if the stiffness of the cement milk would be insufficient. The authors performed small sized model tests of static axial compressive loading for single piles installed in dry sand. We propose a design method of an end shape for small-diameter steel-pipe piles used in foundations of small buildings. Then, actual size loading experiments are performed to confirm validity of the improved pile tip.

LABORATORY EXPERIMENT

Model piles and series of test

A steel pipe, 48.6 mm in diameter (D) and 3.2 mm in thickness (t), was used as a test pile. The length of the pile was 600 mm and the length of embedment (H) was 243 mm ($5D$). To eliminate the frictional resistance, the pile surface was coated with Teflon. Fig. 1 and table 1 show the test piles' shapes and details. The steel pipe is used as the open end pile (OP), and the steel pile attached a steel disk (48.6 mm in diameter) at the tip is used as the closed end pile (CP). A test series of S is carried out in order to discuss the influence of the pile end's opening. At the pile tips of the S-series, holed disks with an external diameter (D_e) of 48.6 mm and inner opening diameters (D_o) of 15, 25 and 30 mm are attached. Furthermore, test series of P are executed to investigate the effect of the pile end's area. Holed disk plates with an opening diameter (D_o) of 32.2 mm and external diameters (D_e) of 58.3, 67.6 and 75.9 mm are fixed to the pile tips of the P-series. Table 1 shows various factors of the test piles. An area ratio (r_A) is the ratio of an end area to the area of the closed end pile (CP).

Method of preparing model ground

A steel circular test tank with a diameter of 50mm and depth of 700mm is used. No. 5 silica sand in dry condition is used for the model ground, and the test ground is prepared by the air pluviation technique with double nets for dispersion. The characteristics of the model ground are shown in table 2.

In order to produce the approximate peripheral ground condition of the pile tip of the prebored pile construction method, preparation of the model ground and installing of the test pile is executed as follows.

1. The model ground is built up until the pile-end position + 5 mm.
2. The test pile is set and is driven 5 mm by light tapping.
3. The model ground is filled up to the surface.

Converted N-values, calculated by the amount of one fall's displacement of SPT, are shown in Fig. 2. From Fig. 2, the average of the N-value ($\overline{N}$) of the pile end (H = 243 mm) is estimated $N = 2$.

Loading and measurement method

For axual loading, a displacement controlling type loading device is used (see Fig. 3), and the loading speed is 1 mm/min. The pile head load and displacement are measured in intervals of 3 seconds by load

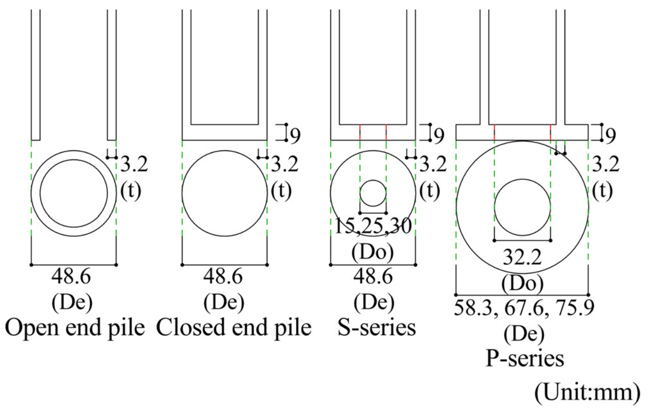

Table 1. Various factors of test piles

Series	Symbol	Area ratio of pile end (r_A)	Opening diameter of pile end D_o (mm)	External diameter of pile end D_e (mm)
Open end pile	OP	0.25	42.2	48.6
Closed end pile	CP	1.00	-	48.6
S-series	S-15	0.91	15.0	48.6
	S-25	0.74	25.0	48.6
	S-30	0.62	30.0	48.6
P-series	P-58	1.00	32.2	58.3
	P-68	1.50	32.2	67.6
	P-76	2.00	32.2	75.9

Table 2. Various factors of model ground

Sand	Silica sand (No.5)
Method	Air pluviation
Density (ρ)	1760 kg/m^3
Void ratio (e)	0.512
Relative density (D_r)	87.50 %
Internal friction angle (φ)	45°

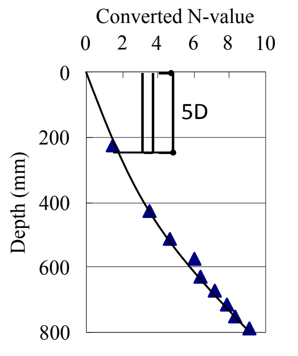

Fig. 2 Distribution of N-values

cell and displacement gages at 2 points. The vertical earth pressure at three points of the bed of the test tank is measured to examine the situation of the pile tip load transmitted within the tank.

In this laboratory experiment, the resistance and the displacement of the pile end are almost equal to the values of the pile head, because the pile length is relatively short and the frictional resistance of the pile surface is exceedingly small. Accordingly, in this paper , the pile head load and pile head displacement are estimated as the pile end resistance and the pile end displacement, respectively.

RESULTS OF LABORATORY EXPERIMENT

Figs. 4 to 7 show the test results of the S-series and P-series, the relationships between the pile end resistance (R) and dimensionless displacement (δ/D, δ: displacement of pile end, D: diameter of pile body), and between the average vertical earth pressure at the bed (σ_v) and dimensionless displacement (δ/D). The results of the open end pile (OP) and the closed end pile (CP) are added to the figures.

In Japan, the end bearing capacity of a single pile is calculated by Eq. 1 which is generally used in pile foundation design.

$$R_p = \alpha \cdot \overline{N} \cdot A_p \qquad (1)$$

Where, R_p is the end bearing capacity, α is the bearing capacity factor, $\overline{N}$ is the average of N-value at pile end and A_p is the sectional area of

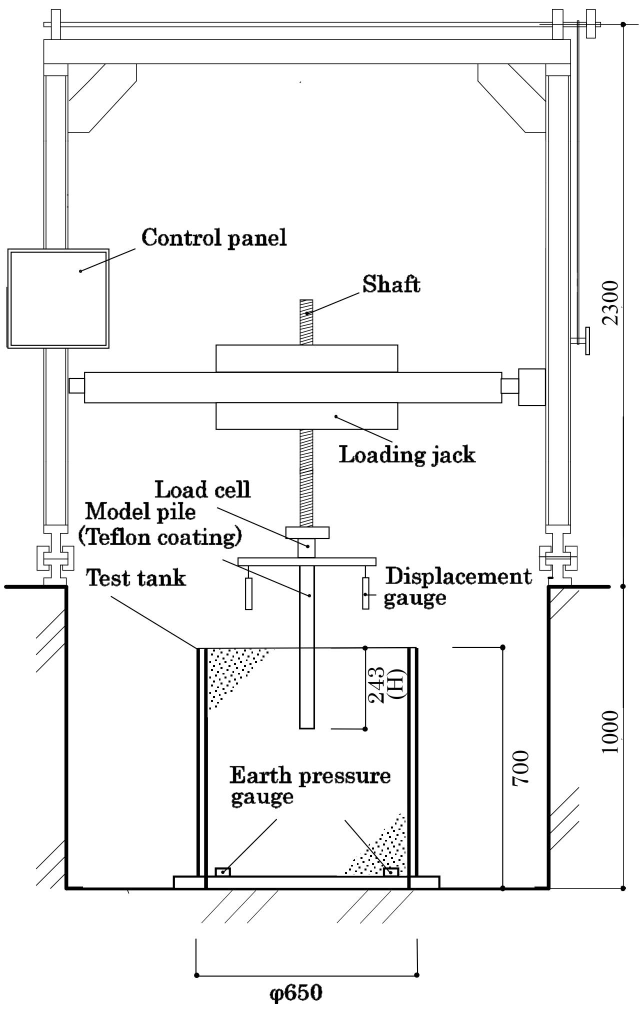

Fig. 3 Experimental apparatus

the pile tip. Usually, the end bearing capacity, which is equal to the second-limit-resistance (regarded as an ultimate bearing capacity), is given when the pile-end displacement reaches 10 % of the diameter. Table 3 shows the key values of the results. The standard value of the bearing capacity factor α for the prebored construction method is α=200. In addition, the standard value of α for the driving construction method is α=300.

Closed end pile and open end pile

As for the pile tip resistance (R) of the closed end pile (CP), the R value is increasing from the loading initial stage. The end bearing capacity (δ/D = 0.1) is R_p = 1.84 kN, and the end bearing capacity factor is α = 495. These are sufficient values for end resistance of the prebored construction method.

In the case of the open end pile (OP), the pile end resistance (R) does not large even if the dimensionless displacement (δ/D) reaches 0.1. The end bearing capacity is R_p = 0.15 kN, and the bearing capacity factor is α = 11.5. These values are only 8 % of the closed end pile's.

The vertical earth pressure (σ_v) of CP is increasing from the loading initial stage, as well as the R-δ/D relation curve. The overburden pressure at the bottom is presumed 12.1 kN/m^3. When the dimensionless displacement (δ/D) is 0.1, the σ_v value indicates 2.7 kN/m^3, and this value is about 1/3 of the overburden pressure at the bottom. In the CP pile, the change of the earth pressure (σ_v) is small, but the stress produced by deformation of a pile end is transmitting to the bottom from the early stages of loading. On the other hand, in the case of the OP, only a small stress is transmitted even when δ/D reaches to 0.2.

S-series and P-series

In the S-series, the larger the opening diameter of D_o at the pile end, the smaller the pile end resistance value. The resistance of S-15 shows almost same value of CP's, and the end pile capacity R_p and the bearing capacity factor α of S-15 are 1.71 kN and 510, respectively. This value is 93 % of CP's.

In case of P-58, the external diameter of the disk plate is larger than the diameter of the upper part of the pile body. However, the opening diameter is almost same as the S-30's. Accordingly, the area ratio of the pile end is 1.0 in P-58. The R_p value of P-58 is indicated 40% of CP's. This phenomenon shows that the end bearing capacity is affected by the opening even if the end area is the same. Meanwhile, the R_p value of P-58 is about 1.6 times larger than that of S-30. This result is signifies that the end disk plate contributes to provide for the large end bearing capacity.

Table 3. Results of laboratory experiments

Symbol	Aperture ratio of pile end (r)	δ/D=0.1	
		R_p (kN)	α(kN/m^2)
OP	0.25	0.15	39
CP	1.00	1.84	495
S-15	0.91	1.71	461
S-25	0.74	0.70	188
S-30	0.62	0.51	138
P-58	1.00	0.85	229
P-68	1.50	2.03	546
P-76	2.00	3.31	893

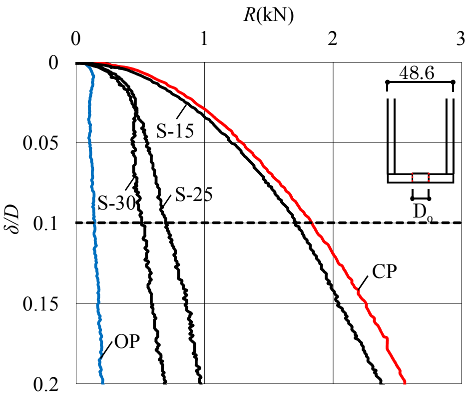

Fig. 4 Relationship between displacement and pile end resistance (S-series)

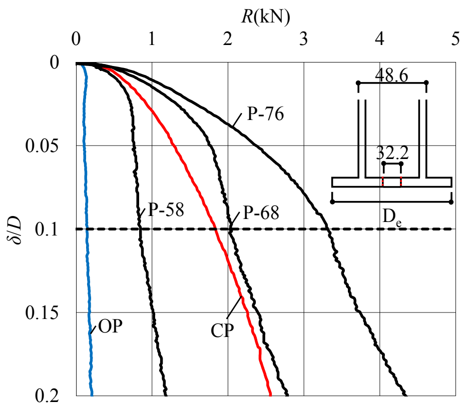

Fig. 5 Relationship between displacement and pile end resistance (P-series)

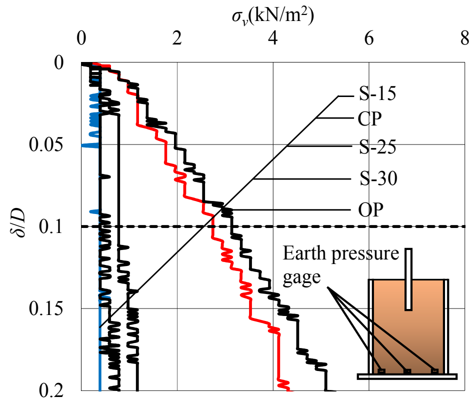

Fig. 6 Relationship between displacement and vertical earth pressure (S-series)

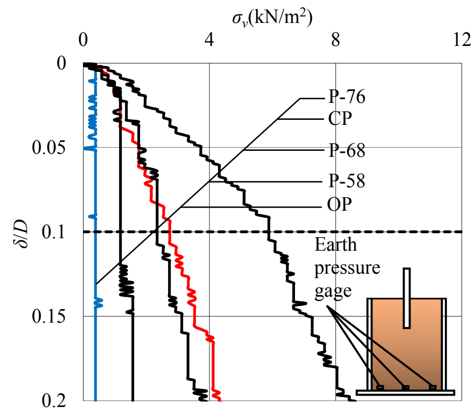

Fig. 7 Relationship between displacement and vertical earth pressure (P-series)

In the vertical earth pressure (σ_v) of the S-series, when the opening diameter (D_o) become large, the σ_v value become small. Meanwhile in the P-series, when the external diameter (D_e) become large, the σ_v value also become large.

Fig. 8 shows the relationship between the aperture ratio of the pile tip (r) and the bearing capacity factor (α). The α value is calculated by eq. 1, and A_P is the sectional area of the pile body. The aperture ratio r is the ratio of the opening area to the whole area of the pile tip. In the S-series, when aperture ratios r are larger than 0.27, α values become smaller than the standard value of the prebored contruction method. However in the P-series, all test results show larger values than those of S-series, and are also larger than the standard values.

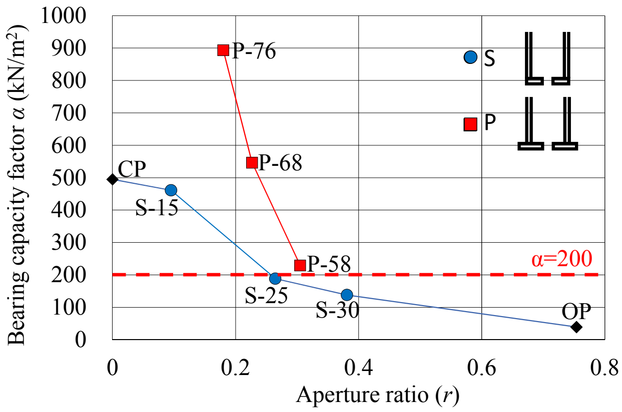

Fig. 8 Relationship between a bearing capacity factor α and aperture ratio r

Table 4. Various factors of test piles for field test

	S-pile	C-pile
Average of N-value at Pile end ($\overline{N}$)	15.8	8.8
Diameter of pile body D (mm)	165.2	
Diameter of opening D_o (mm)	85.2	
External diameter of disk plate D_e (mm)	225.2	

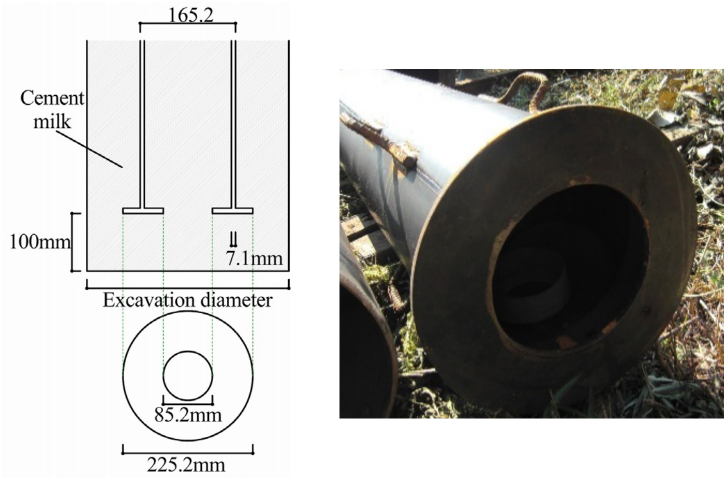

Fig. 9 Pile tip shape of field test

FIELD EXPERIMENT

Test pile and field

According to the results of the laboratory experiment, the end disk plate is effective for improvement in the end bearing capacity of the prebored pile construction method. However, the larger disk plate might scrape the soil off a bored hole, and an enough opening is needed to fill the inner space of the pile with the cement milk. We designed the end shape of pile for field experiments as follows.

1. The area ratio (r_A; r_A=A/A_0, A is actual area of pile and A_0 is sectional area of the pile body) should be more than 1.0 (r_A>1.0).
2. The digging diameter ratio (r_D; r_D=D_e/D_D, D_e is external diameter of the end disk plate, D_D is digging diameter) should be less than 0.8 (r_D<0.8).
3. The opening diameter (D_o) of the end disk plate should be more than 80 mm (D_o >80 mm)
4. The aperture ratio (r; r =D_o^2/D_e^2) should be less than 0.3 (r<0.3).

Above manner is possible to apply the general design of the end shape of small-diameter steel-pipe piles for the cement milk pile construction method.

The diameter of the test pile is 165.2 mm at the pile body, and the external diameter of the end disk plate is 225.2 mm and the opening diameter is 85.2 mm (see table 4 and Fig. 9).

Two field loading tests are carried out. One of the test piles, named S-pile is embedded into clayey sand and another pile, named C-pile is fixed on sandy clay. The test field is located in Morokawa City, in the north area of the Kanto plains. The boring logs and distribution of N-values are shown in Fig. 10. The averages of N-value at the embedment positions ($\overline{N}$) are 15.8 in the S-pile and 8.8 in the C-pile, respectively.

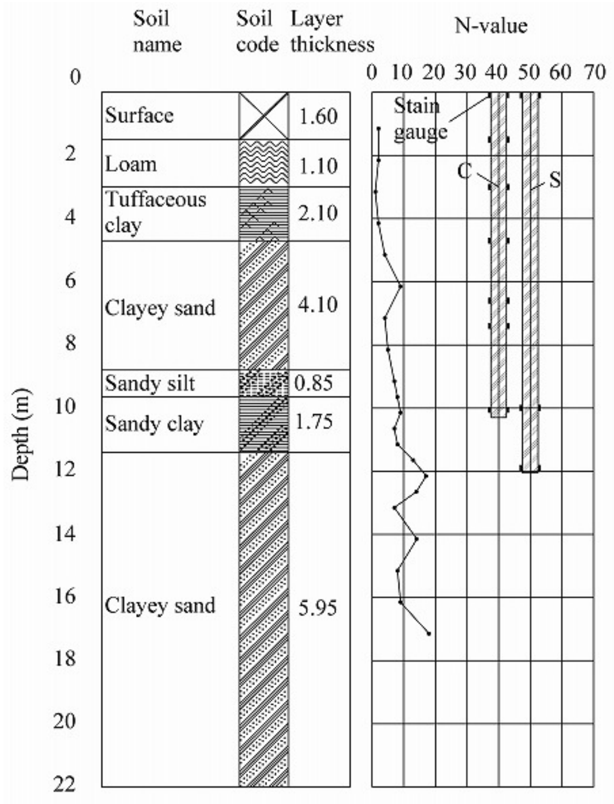

Fig. 10 Boring logs of field test

Loading and measurement

The pile installation is performed by the cement milk pile construction method. After filling up cement milk into the prebored hole, the pile is installed carefully till the embedment length. Static axial load tests are executed according to the test manual produced by the Japanese Geotechnical Society using the anchor-pile-system. The strain and displacement of the pile tip are measured, and the pile end load is converted by the strain.

Results of field experiment

The relationships between the pile end loads (R) and dimensionless displacements (δ/D) are shown in Fig. 11.

As for the S-pile, the end bearing capacity (R_P), which is the pile tip resistance when δ/D=0.1, indicates 104 kN and the bearing capacity factor (α) is 307. And as for the C-pile, R_P = 128 kN and α = 680. From these results, we can confirm the validity of the disk plate added to the pile tip.

Fig. 12 shows the pile tip situation which is dug out after the test. It seemed that the pile tip has solidified united with cement milk, and also has enough stiffness. The pile tip resistance must be owing to bearing pressure of the pile tip area, and the friction with soil around the pile tip zone may contribute also. Namely, It is considered that the big block made by the end disk plate and cement milk has influenced exertion of the end bearing capacity of pile.

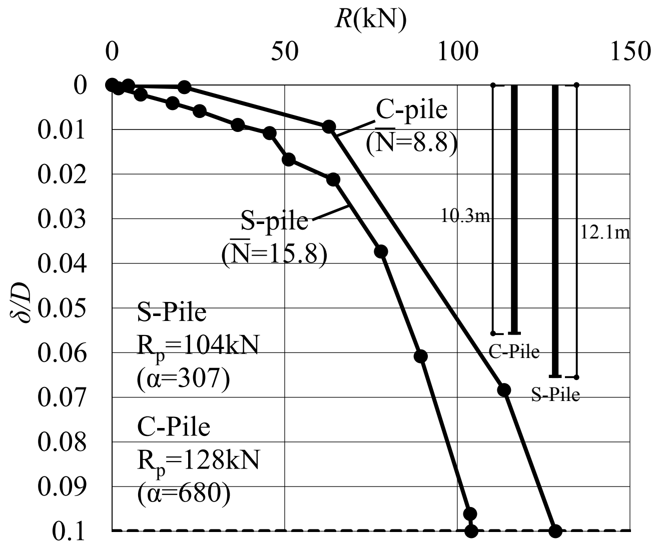

Fig. 11 Relationship between displacement and pile end resistance (S-pile and C-pile)

Fig. 12 Pile tip situation (S-Pile)

CONCLUSION

In the cement milk pile construction method, there is some possibility of decreasing the end bearing capacity due to the opening of the pile end. Adding a large disk plate to the pile end is one of the solution of the problem. In this paper, we examined the influence of the openings and proposed an improvement method by the laboratory load tests. Furthermore, we confirmed the validity of the pile tip disk by actual sized field experiments. The piles of which the tips were improved by the disk plates exhibited large and sufficient end bearing capacities.

ACKNOWLEDGEMENTS

Special thanks are due to Mr. K. Minagawa and Mr. Y. Kanahira, System-Keisoku Co., Ltd., for their technical support in the field test. And we would like to acknowledge Mr. Ishikawa, students of Nihon University, for his cooperation in the laboratory experiment.

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