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Pile Loading Tests
at Osaka Amenity Park Project

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ABSTRACT

Three kinds of pile loading tests were conducted at Osaka Amenity Park Project. The sizes of the instrumented test piles were 38.5 m in length and 1.2 m in diameter. The outline of each test was as follows.
(1) Vertical loading test: Vertical load of 19.6 MN (2,000 tf) was applied to the top of one pile. Friction cut had been done for the pile surface from ground surface to the depth of 17 m.
(2) Pulling tests: Pulling forces of 4.9 MN (500 tf) and 9.8 MN (1,000 tf) were applied to the top of one pile. The pile was used as one of four anchor piles for the vertical loading test. The first force of 4.9 MN (= 19.6 MN / 4) was a reaction force. The second force of 9.8 MN was applied to obtain the ultimate pulling resistance.
(3) Simplified loading tests: A pair of upward and downward forces of about 7.84 MN (800 tf) was applied to the bottoms of two piles. Friction cut had been done for the surface of one pile from ground surface to the depth of 17 m. The mutually opposite forces were obtained by expanding the cell of a jack placed at the bottom of the pile. Skin friction and end bearing were separated by the jack. No anchor pile and no reaction beam were needed for conducting the tests. The word of 'simplified' is derived from the simplicity of the test.

In all tests mentioned above the distribution of axial load and the displacements of the top and bottom of the pile were measured. The information obtained was as follows.
(1) The relationships between skin friction and pile displacement in two simplified loading tests were in good agreement with that in the vertical loading test at each pile section.
(2) The relationships between pile tip resistance and settlement in two simplified loading tests were in good agreement with that in the vertical loading test.

1. INTRODUCTION

In Osaka Amenity Park Project a group of large scale buildings for complex purposes is expected to be constructed at Tenma in Osaka City. A series of pile loading tests was conducted to obtain the basic information for the pile design. Conducted were three kinds of tests, namely (1)vertical loading test, (2)pulling test and (3)simplified loading test. In the simplified loading test, skin friction and end bearing of the pile were loaded using each other as a reaction force. The loading was made by expanding the cell of a jack placed at the bottom of the pile.

The paper presents the typical test results and the comparison of the relationships of pile displacement with skin friction and end bearing between the tests.

2. OUTLINES OF PILE LOADING TESTS

Soil Conditions and Pile Profile

Fig.1 shows the soil conditions and pile profile. The boring was done at two points. The boring data presented are groundwater level, SPT *N*-value, effective overburden pressure σ_v', unconfined compressive strength q_u, and consolidation yield stress p_c.

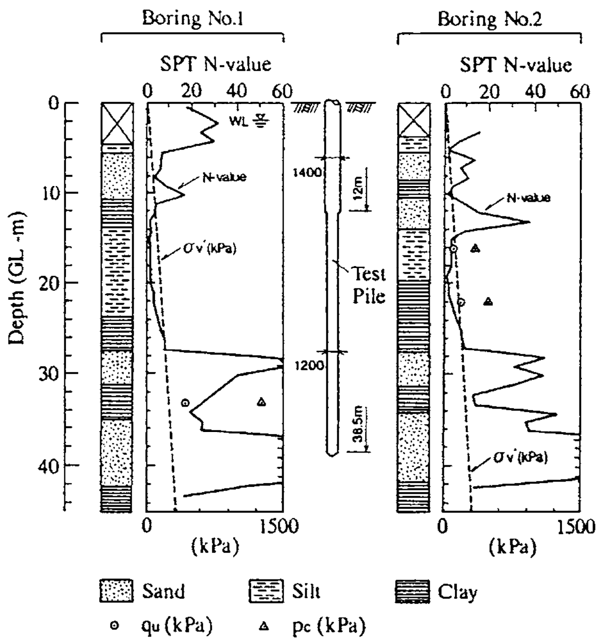

Fig.1 Soil Conditions and Pile Profile

The test site was located near the river. The soil consists of alluvium and diluvium. The alluvium has been deposited to GL–27 m. The sequence of strata of the diluvium, which has been deposited under the alluvium, is sand–gravel, clay, sand, clay and sand. The sand–gravel stratum of GL–27 m to GL–31 m, where the SPT *N*–value is more than 50 in some part, was not suitable for a bearing stratum of the pile because of its relatively small thickness. In the sand stratum of GL–35 m to GL–42 m, the thickness of the layer having the SPT *N*–value of more than 50 is relatively large. However, its performance when used for a bearing stratum was not clear. One of test aims was to assess this performance. The alluvial clay and silt strata are overconsolidated because $p_c > \sigma_v'$. This may have been caused by the fact that groundwater level fell below GL–10 m by pumping up underground water and subsequently recovered to the original level.

The instrumented test piles were cast in place concrete piles made by reverse circulation drill method. The sizes of the piles were 38.5 m in length and 1.2 m in diameter. Pile diameter, however, was 1.4 m from ground surface to GL–12 m because of using a stand pipe. Pile tip was socketed by about 1.5 m into the sand layer of GL–37 m to GL–42 m, which would be a bearing stratum.

Test Types

Fig.2 shows the arrangement plan of six piles used in the tests. These piles were in between two boring points. A series of pile loading tests was (1)vertical

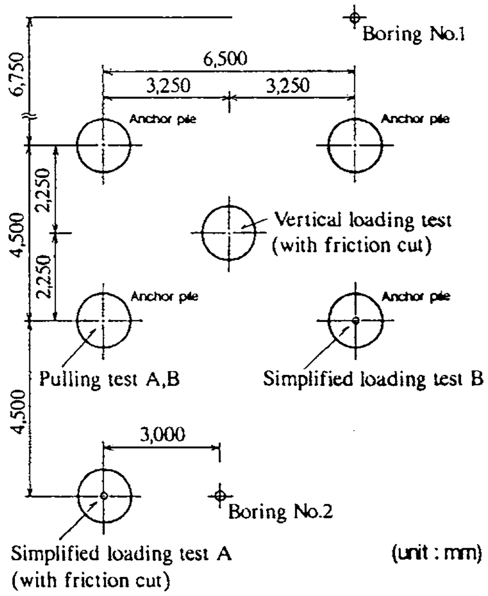

Fig.2 Arrangement Plan of Test Piles

loading test, (2)pulling test A, (3)pulling test B, (4)simplified loading test A, and (5)simplified loading test B. Two piles used for the pulling tests and the simplified loading test B were anchor piles for the vertical loading test. In pulling tests, the pile for the test A was loaded by a reaction force which was a quarter of the vertical load applied in the vertical loading test. The test B was subsequently conducted to obtain the ultimate pulling resistance using the same pile. The order of conducting the tests was (5), (4), (1) and (2), and (3). Friction cut had been done from ground surface to GL–17 m for the surface of the piles used for the vertical loading test and the simplified loading test A. This was because the base level of foundation slab of the buildings was expected to be GL–17 m.

3. VERTICAL LOADING TEST

Loading Method

The maximum vertical load of 19.6 MN (2,000 tf) was applied to the top of the pile. This maximum load was determined to obtain the ultimate bearing capacity of the pile. The pile was loaded step–by–step under a load increment of 1.96 MN (200 tf). The overall loading was cyclic where each maximum load increased every cycle and the minimum load was zero. The virgin loads were maintained for 60 min. Four anchor piles were used. The test was conducted 31 days after pile construction.

Test Results

Fig.3 shows the load–settlement curves. P_0 and P_p are the applied pile top load and pile tip resistance (the axial load at GL–37 m) respectively. S_0, S_m and S_p are the settlement at pile top, in the middle of the pile (GL–18 m) and at pile tip (GL–37 m), respectively. The reference bearing capacity, which is the value of P_0 at S_p = 10 % of pile diameter of 1.2 m, would be 20.58 MN (2,100 tf) according to the extrapolation of the *log* P_0–*log* S_p curve. The long term allowable bearing capacity P_a, which is 1/3 of the reference bearing capacity, would be 6.86 MN (700 tf). It was found that this value of P_a of the test pile was about 2.5 times that expected in the design. When the value of P_0 exceeded 9.8 MN (1,000 tf), S_0 and S_m were much larger than S_p. This was because the pile had crushed at GL–28.5 m, where the compressive strength of the concrete was relatively weak. The use of a special tremie pipe for the simplified loading tests would make the concrete weak.

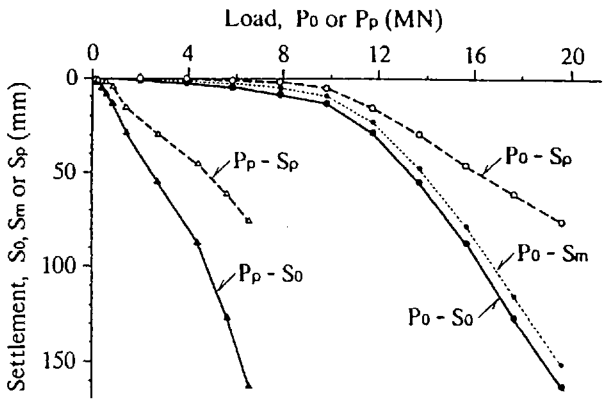

Fig.3 Load–Settlement Curves in Vertical Loading Test

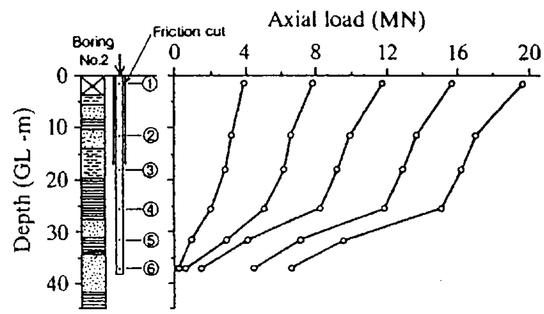

Fig.4 Load Distribution Curves in Vertical Loading Test

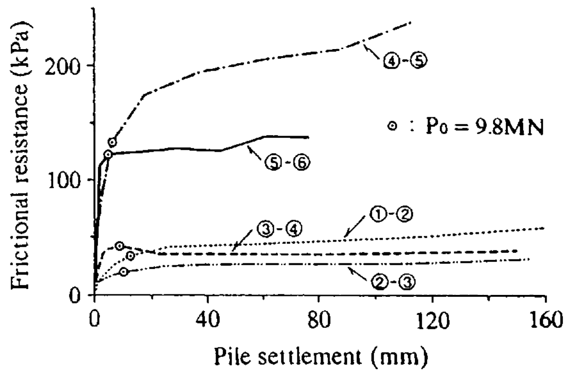

Fig.5 Relationship between Skin Friction and Pile Settlement at Five Pile Sections in Vertical Loading Test

This fact, however, does not influence the pile design because the value of P_0 when the concrete crush had occurred was much larger than that expected in the design.

Fig.4 shows the distribution curves of axial load. In spite of friction cut of pile surface from ground surface to GL–17 m, the 1–3 section had the maximum skin friction of more than 2.94 MN (300 tf). The 3–6 section had the maximum skin friction of about 9.8 MN (1,000 tf).

Fig.5 shows the relationship between skin friction and pile settlement at each pile section. Pile settlement is the value in the middle of the section. The open circles indicate the points at P_0 = 9.8 MN (1,000 tf). Skin friction at each section had almost reached the ultimate value after this point.

4. PULLING TESTS

Test Types

The test A was conducted to measure in detail the pulling resistance and upward movement of the pile. The test pile was one of four anchor piles used for the vertical loading test. The loading was made by using a reaction force in the vertical loading test. The test B was subsequently conducted to obtain the ultimate pulling resistance using the same pile. 36 reinforcing bars had been put in the pile to resist the pulling force. The weight of the pile was about 0.66 MN (67 tf) when deducting the buoyancy of underground water.

Loading Method

The maximum pulling force of 9.8 MN (1,000 tf) was applied to the top of the pile in the test B. The piles were loaded step-by-step under load increments of 0.49 MN (50 tf) and 0.98 MN (100 tf) in the tests A and B respectively. The overall loading was cyclic. The virgin loads were maintained for 60 min. The maximum pulling force was maintained for 240 min in the test B. The tests A and B were conducted 19 days and 41 days after pile construction, respectively.

Test Results

Fig.6 shows the relationship between pulling force P_0 and upward movement U_0 at pile top. The P_0–U_0 curve for the test B fits very well with that for the test A. At P_0 = 9.8 MN (1,000 tf) in the test B, the increment of U_0 from 60 to 240 min after applying the load was very small. Skin friction would not reached the ultimate value judging from this stability. Consequently, the pulling resistance of more than 9.8 MN (1,000 tf) or 65 kPa (6.6 tf/m²) was expected for the test pile. The maximum pulling force expected in the seismic design is 36 kPa (3.7 tf/m²).

Fig.7 shows the distribution curves of axial load in the test A. When P_0 < 2.94 MN (300 tf), the inclination of each curve, i.e. skin friction, was uniform. When P_0 > 2.94 MN (300 tf), on the other hand, some axial loads were abnormally large. The axial load was calculated

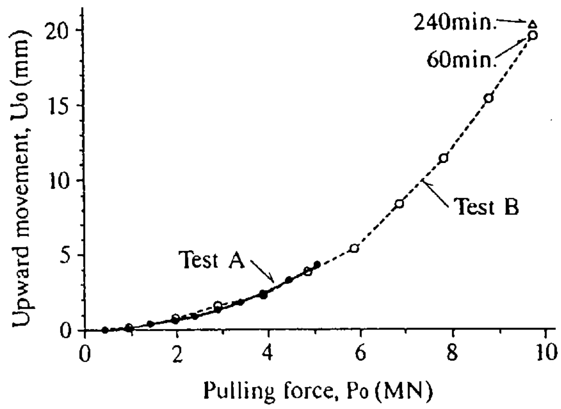

Fig.6 Relationship between Pulling Force and Upward Movement at Pile Top in Pulling Tests

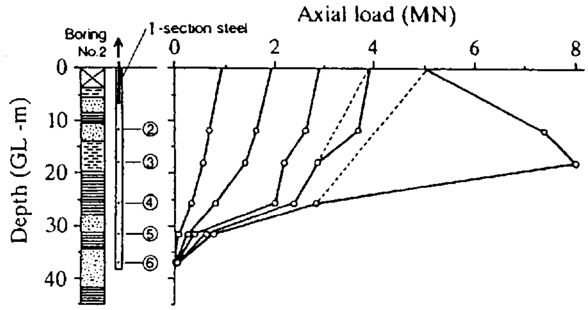

Fig.7 Load Distribution Curves in Pulling Test A

on the assumption that the axial strain was uniform within the cross section of the pile. The occurrence of concrete cracks would cause the abnormality. It was impossible to obtain the skin friction for all soil layers.

5. SIMPLIFIED LOADING TESTS

Outline of Test Method

Fig.8 schematically illustrates the simplified loading test. Skin friction and end bearing of the pile are loaded using each other as a reaction force. The loading is made by expanding the cell of a jack placed at the bottom of the pile. Skin friction and end bearing are separated by the jack. The displacements of the inner and outer pipes are the downward and upward movements at the bottom, respectively. The outer pipe is pressurized to apply the load. No anchor pile and no reaction beam are needed for conducting the tests. The word of 'simplified' is derived from the simplicity of the test. The test method enables to obtain the mechanical behaviour of the bearing stratum with certainty.

Osterberg (1984, 1991) reported the test examples

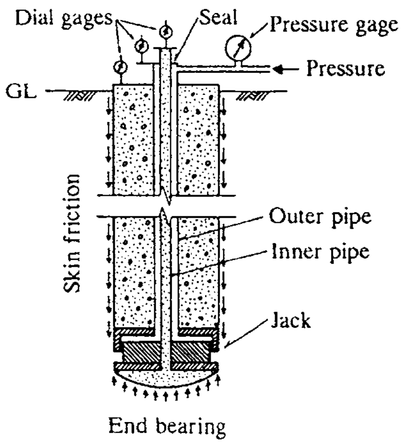

Fig.8 Schematic Diagram of Simplified Loading Test

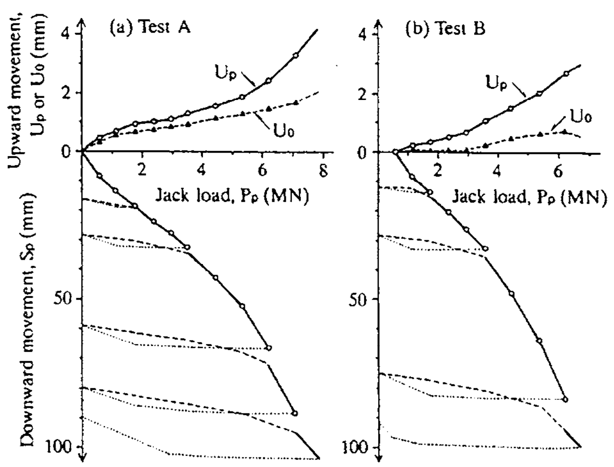

Fig.9 Relationships of Jack Load with Upward and Downward Movements in Simplified Loading Tests

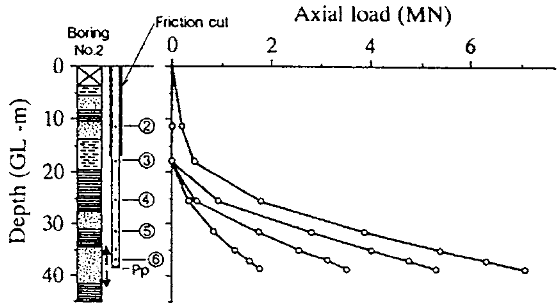

Fig.10 Load Distribution Curves in Simplified Loading Test A

of mainly cast in place concrete piles. Arai et al. (1990) and Ogura et al. (1991) reported the test results of precast piles. The tests presented in this paper were the first application to cast in place concrete piles in Japan. The test method employed was a use of the Osterberg's method. The tests were conducted under the bad condition that the jack was installed through the clay suspension. The pressure medium was water mixed with a small amount of water-miscible oil to protect the seals and the pump.

Test Types

The test A with friction cut and the test B without friction cut were conducted.

Loading Method

A pair of the maximum upward and downward forces of about 7.84 MN (800 tf) was applied to the bottoms of two piles. The overall loading was cyclic. The virgin loads were maintained for 60 min. The tests A and B were conducted 15 days and 19 days after pile construction, respectively.

Test Results

Fig.9 shows the relationships of the applied jack load P_p with pile tip settlement (i.e. downward movement) S_p and upward movements at pile tip U_p and at pile top U_0 in the tests A and B. In both tests the loading had stopped due to the leakage of the jack pressure when the value of S_p exceeded a little more than 100 mm. The maximum measured values of U_p were 3 to 4 mm. This small values indicate that the skin friction had not reached the ultimate value. Consequently, the skin friction of more than 7.84 MN (800 tf) was expected for the test pile. In the test B the displacements at P_p = 0.59 MN (60 tf) was zero because the concrete which surrounded the jack did not separate by this load.

Fig.10 shows the distribution curves of axial load in the test A. The inclination of the curve, i.e. skin friction, of the 3–4 section was smaller than those below this section. This was because the 3–4 section corresponded to the alluvial clay stratum having a small shear modulus.

6. COMPARISON BETWEEN TESTS

This section presents the comparison of the relationships of pile displacement with skin friction and end bearing between three kinds of pile loading tests.

Skin Friction

Fig.11 shows the relationships between skin friction and pile displacement at three pile sections. Pile settlement is the value in the middle of the section. The 3-4, 4-5 and 5-6 sections correspond to the depths of GL-18 to 25.5 m, GL-25.5 to 31.5 m and GL-31.5 to 37 m, respectively. As shown in the figure, the curves of two simplified loading tests fit reasonably with that of the vertical loading test at each section. The stiffness of skin friction in the pulling test B was higher than those in other tests at each section. This may have been because the pulling test B was conducted by reloading after the pulling test A. Unfortunately, the curves of the pulling test A were not obtained.

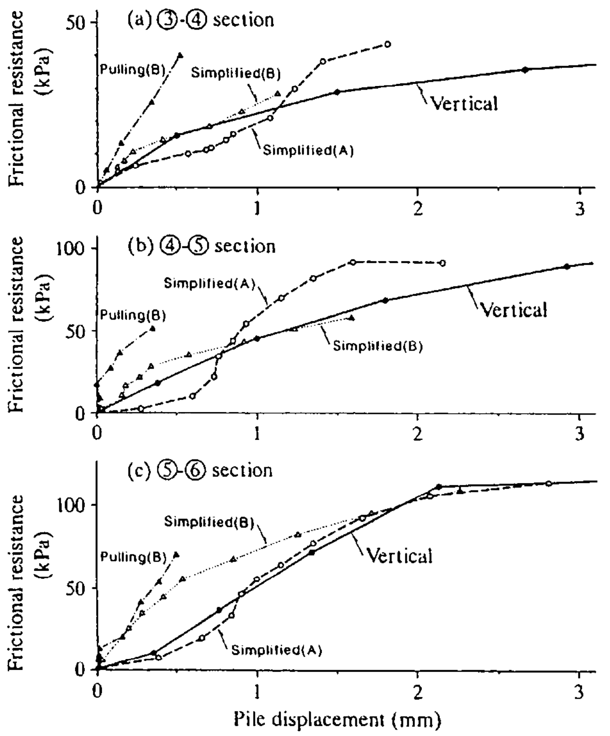

Fig.11 Relationships between Skin Friction and Pile Displacement at Three Pile Sections

End Bearing

Fig.12 shows the relationship between unit tip resistance q_p (= P_p/A_p) and tip settlement-diameter ratio S_p/D_p. The values of pile tip diameter D_p and the sectional area of pile tip A_p are 1.2 m and 1.13 m^2 respectively. As shown in the figure, the tip resistance-settlement relationships in two simplified loading tests were in good agreement with that in the vertical loading test. Much lower costs and shorter preparatory periods were needed for the simplified loading tests, compared with the vertical loading test.

The reliability of the value of P_p in the simplified loading test may be higher than that in the vertical loading test. This is because the value of P_p is calculated using the jack pressure in the simplified loading test, while calculated using the axial strain taking pile compressibility into account in the vertical loading test.

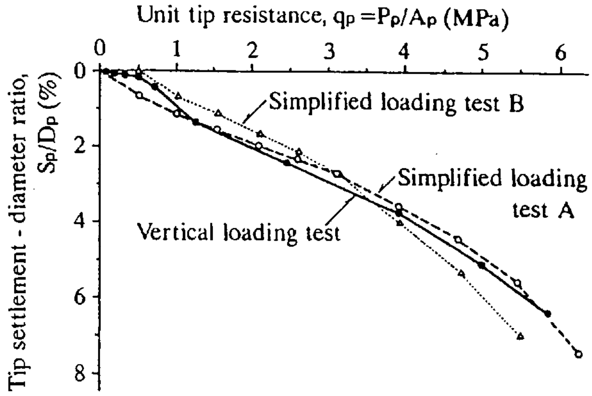

Fig.12 Relationship between Unit Tip Resistance and Tip Settlement-Diameter Ratio

7. CONCLUSIONS

Three kinds of pile loading tests were conducted at Osaka Amenity Park Project. These were the vertical loading test, the pulling test and the simplified loading test. The information obtained was as follows.

(1) In the vertical loading test, the skin friction at any pile section had almost reached the ultimate value.

(2) In the pulling tests, it was impossible to obtain the skin friction at all pile sections because concrete cracks occurred within the pile when large pulling forces were applied.

(3) In the simplified loading tests, the mechanical behaviour of the bearing stratum was obtained with certainty in spite of not enough loading.

(4) The relationships between skin friction and pile displacement in two simplified loading tests were in good agreement with that in the vertical loading test at each pile section.

(5) The relationships between pile tip resistance and settlement in two simplified loading tests were in good agreement with that in the vertical loading test.

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