Deep Foundations on Bored and Auger Piles, Van Impe (ed.)

Bearing capacity of bored pile packed with iron and steel slag using precast concrete pile

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ABSTRACT: The bearing capacity of a pile with packing material around it was studied by on-site tests with special emphasis on the expandability and consolidating ability of iron and steel slag. Excellent bearing capacity was obtained by using iron and steel slag as the packing material, which was superior to the bearing capacity obtained by the conventional cement milk piling method. Particularly, a significant increase in bearing capacity was obtained with the passage of time, which cannot be obtained by other packing materials. The bearing capacity increased regardless of whether the surrounding ground consisted of sandy soil or clayey soil. This effect was more pronounced in precast concrete nodular piles than in precast concrete straight piles. Large skin friction developed at an early stage in wet ground up to the groundwater level.

1 INTRODUCTION

By-products are generated such as blast furnace slag during the ironmaking stage and steelmaking slag during the steelmaking stage of iron and steel production. Some of these slags, particularly steelmaking slag before the aging process, have physical properties such as strength, specific gravity, hardness and expandability that are different from those of natural materials.

Until now, properties such as consolidation and expandability were considered to be undesirable when steelmaking slag was used. However, it was observed that the bearing capacity of the foundation pile was enhanced by packing slag around a precast concrete pile. Keeping this point in mind, we worked toward the development and realization of the bored piling method.

The high bearing capacity obtained from model tests of foundation piles carried out until now using iron and steel slag[1),2)] was confirmed by carrying out on-site tests using large, actual piles in various kinds of ground.

The aim in this study was to determine the optimum combination of the type of ground, the type of packing slag and the shape of precast concrete pile that would demonstrate the best bearing capacity for the pile constructed by the bored and slag-packed piling method using iron and steel slag.

The aim was also to examine the effects of loading history on the bearing capacity.

This report describes the bearing capacity of a precast concrete pile packed with iron and steel slag (hereafter called the "bored and slag-packed piling method") obtained by on-site tests.

2 OVERVIEW OF TESTS

2.1 *Kinds and basic characteristics of iron and steel slag*

The kinds of iron and steel slag used in the on-site tests were steelmaking slag (converter slag) before the aging process and blast furnace slag (granulated blast furnace slag). The slag packed around the pile during the construction work was steelmaking slag only and a mixture of two kinds of steelmaking slag. The grain size distribution curve of each kind of slag is shown in Fig. 1, the various kinds of packing slag are shown in Table 1 and the chemical composition of slag in Table 2.

The results of the expansion test of the steelmaking slag are shown in Fig. 2, while the results of triaxial compression tests (CD tests) are shown in Table 3.

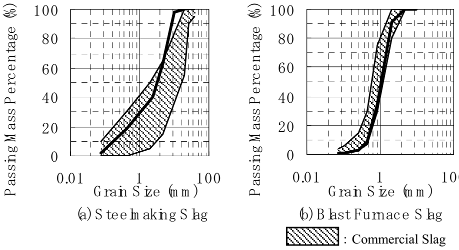


Fig. 1. Grain size distribution curve

Table 1. Various kinds of packing slag

Steelmaking Slag:	100% Steelmaking Slag
Mixed Slag:	70% S.S.+ 30% B.F.Slag

Table 2. Chemical composition of Slag (mass %)

	S_iO_2	C_aO	Al_3O_3	M_gO	$T\text{-}F_e$	S	M_nO	T_iO_2
Steelmaking Slag	11.3	37.3	3.9	15.7	20.4	0.04	6.1	1.5
B.F.Slag	33.8	42.0	14.4	6.7	0.3	0.84	0.3	1.0

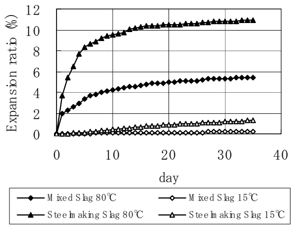


Fig. 2. Result of expansion test

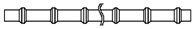
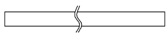
Table 3. Result of triaxial test(CD test)

	C kPa	φ °
Steelmaking Slag	127	50.9
Mixed Slag	199	43.2

2.2 *Shape, dimensions and kinds of precast concrete pile*

Table 4 shows the shape, dimensions and kinds of precast concrete piles used as test piles.

Table 4. Precast concrete pile types

Shape		
Dimensions	Max diameter(Do): 440mm Minimum diameter(D): 300mm Nodular interval: 1000mm Length : 11m,4m	Max diameter(Do): 450mm Length : 11m
Pile type	Nodular Pile A type, B type	Straight Pile B type

2.3 *Construction method*

Construction during the on-site tests was according to the new bored and slag-packed piling method. For comparison with other methods, the construction was also carried out by the conventional bored piling method in which soil cement formed by mixing and stirring cement milk and excavated soil (hereafter called "bored and cement milk-packed piling method") is used as the packing material.

2.3.1 *Bored and slag-packed piling method (new construction method)*

In this method, a precast concrete pile is inserted in a hole excavated using an auger, and iron and steel slag is packed around the pile. This piling method aims to enhance the development of skin friction of the pile through the static compaction effect for ground surrounding the pile due to the consolidation and expansion of the iron and steel slag. The excavation diameter was taken as 700 mm for a bored precast concrete nodular pile of diameter 300 to 400 mm. Fig. 3 shows the construction procedure.

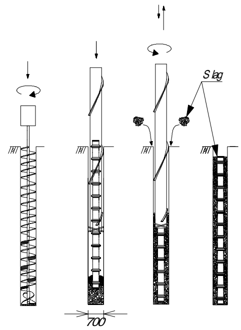


Fig. 3.Bored and slag-packed piling method

2.3.2 *Bored and cement milk-packed piling method (conventional method)*

In this method, a hole is excavated using an auger and cement milk is injected in the hole. The excavated soil and cement milk are mixed and stirred to form soil cement into which the precast concrete pile is inserted. The soil cement becomes integral with the precast concrete pile when it hardens. The excavation diameter was taken as 500 mm for a precast concrete nodular pile of diameter 300 to 400 mm. Fig. 4 shows the construction procedure.

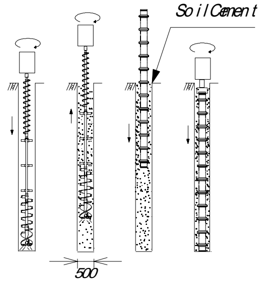


Fig. 4. Bored and cement milk packed piling method

2.4 *Vertical load test pile and evaluation method*

The static axial compressive load tests of single pile were carried out in accordance with the standards of the Japanese Geotechnical Society [3)] (hear after called “the vertical load test”).

The loading equipment used was an anchor pile system. An electro-hydraulic jack was introduced between the loading beam and the test pile. A stage loading arrangement was used with eight or more loading stages. The number of cycles used was four or more, in principle. Fig. 5 shows the loading scheme.

Table 5 shows the standard load step sequence.

The main measurements were applied load, settlement of pile head and pile tip and the strain in the pile.

The bearing capacity was evaluated by comparing the resistance values from the Q-S_h curve when S_h reached 10% of the pile diameter D_b (hereafter called the “Conventional ultimate pile resistance R_{conv}”). Where S_h did not reach 10% of D_b, the maximum load retained for 30 minutes was taken as R_{conv}.

Note that the skin friction of the section, f_i is the value obtained by dividing the difference in axial load between each cross section where the strain gauge was installed with the surface area of the pile (product of diameter at node and π and length of the section).

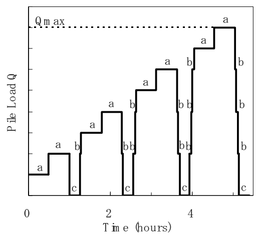


Fig. 5. Loading scheme

Table 5. Standard load step sequence

Rate of loading	During loading	:	planned maximum load / number of step / min
	During unloading	:	Twice the rate used loading stage
Holding time for each loading step	New loading step	:	a constant period not less than 30min(a)
	Unloading or reloading step	:	a constant period not less than 2min(b)
	Unloading to zero load	:	a constant period not less than 15min(c)

3 ON-SITE TESTS OF BORED AND SLAG-PACKED PILING METHOD

3.1 *On-site tests in ground with sandy soil*

3.1.1 *Test method*

Test piles were constructed by the bored and slag-packed piling method in ground consisting mainly of sandy soil and gravelly soil.

The test piles used were of two kinds – the precast concrete nodular pile and the precast concrete straight pile. Two kinds of slag were used as packing material around the pile: steelmaking slag and mixed slag.

To study the change with time of the bearing capacity of each test pile, the vertical load tests were carried out for the same piles cured for 1 month and for 3 months. Table 6 shows the test conditions.

Table 6. Test conditions

Test	Method	Pile type	Material of	Time of a load test	
				1month	3months
S1	Bored	Nodular pile φ440-300,	Steelmaking Slag	○	○
S2			Mixed Slag	○	○
S3		Straight pile φ450,t=65, ℓ=11m	Steelmaking Slag	○	○

3.1.2 *Test ground and locations of installation of test piles*

The test ground was reclaimed ground from the surface to a depth of 5.35 m below ground level with alternate layers of sand with an N-value of 6 and layers of gravel mixed with clayey soil with an N-value of 5 to 16. At levels of 5.35 m to 13.8 m below the ground, the layers were gravel layers with an N-value ranging from 10 to 22. The groundwater level was 2.5 m below ground level.

The tip of the test pile was embedded in a gravel layer 10.7 m below the ground level.

Fig. 6 shows the soil boring log of the test ground and the positions of installed strain gauges on the test pile. The strain gauges were installed at the interface of each layer and on the pile head and pile tip ends.

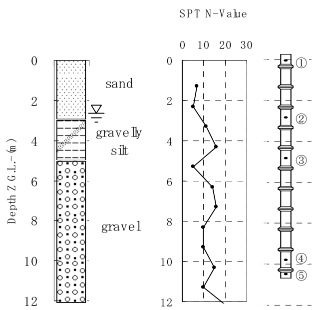


Fig. 6. Soil boring log

3.1.3 *Results of vertical loading tests and discussion*

(1) Results of measurement of pile head load and pile head settlement

Fig. 7 shows the pile head load Q versus pile head settlement S_h curve of each test pile based on the results of the vertical load tests. This Figure shows the Q versus S_h curves for curing periods of 1 month (bold line) and 3 months (broken line).Table 7 shows the change with time of R_{conv} and the R_{conv} of each test pile.

(2) Results of measurement of strain in the pile

Fig. 8 shows the axial load distribution of each test pile and Fig. 9 shows the curve of skin friction of the section, f_i versus the settlement of the section S_i, based on the results of strain measurement of the pile. Fig. 10 shows the change with time of R_{conv}, the tip resistance R_p, and the skin friction R_f.

(3) Discussion on the results

The following points regarding bearing capacity can be understood from the load-settlement relationship:

(a) Comparison of two kinds of packing slag shows that mixed slag had high bearing capacity and it developed 1.3 times the R_{conv} of steelmaking slag at a curing period of one month and approximately 1.4 times the R_{conv} of steelmaking slag at a curing period of 3 months. The bearing capacity increased with the increase in curing period. According to 3 months, the bearing capacity for mixed slag increase by 1.24 times that of 1 month and for steelmaking slag increase by

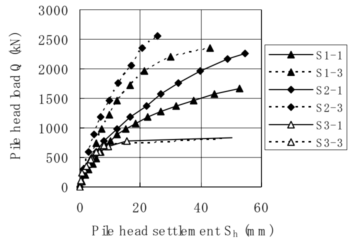


Fig. 7 Q~S_h interaction curve

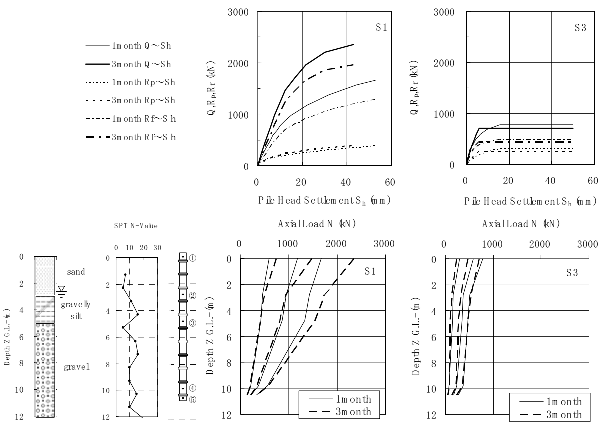


Fig. 8. Distribution map of axial load

Table 7. Change of R_{conv} with time

Conventional ultimate pile resistance R_{conv} (kN)			
Test No.	1month (a)	3months (b)	Ratio (b/a)
S1	1563	2354	1.51
S2	2054	2550	1.24
S3	785	706	0.90

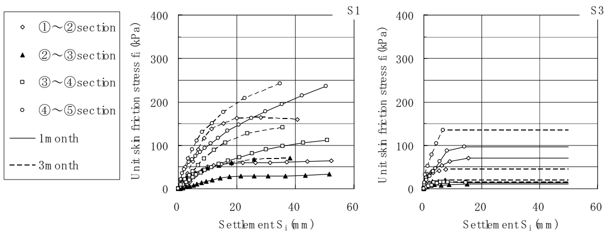


Fig. 9. f_i ~ S_i interaction curve at the section

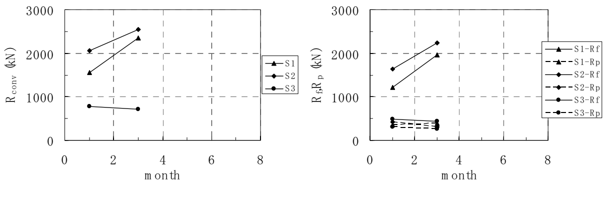


Fig. 10. Change of R_{conv},R_p,R_f with time

1.51 times that of 1 month. (Table 7)

(b) Comparison of the shapes of precast concrete piles showed that the bearing capacity of nodular pile was extremely high compared to that of straight pile. The R_{conv} of the nodular pile was more than two times at a curing period of 1 month and more than 3 times during reloading at a curing period of 3 months compared to the R_{conv} of the straight pile. The change with time of bearing capacity showed an increase of 1.25 times in the bearing capacity of the nodular pile at a curing period of 3 months, whereas in contrast, the bearing capacity of the straight pile decreased to about 0.9 times for the 3 months curing period.

From the distribution of axial loads and the f_i - S_i relationship, the following observations were made:

(c) Comparison of the different types of slag showed that the f_i in the slag in wet earth upper the groundwater level (2.5 m below ground level) appeared faster compared to the slag in earth in the saturated condition at depths below the groundwater level. Furthermore, about 3 times the f_i in mixed slag upper the groundwater level appeared faster compared to the steelmaking slag. However, with the increase in the curing period, the difference in f_i for these two slags reduced so that the ratio became 1.3 times at a curing period of 3 months. The f_i - S_i curve in this case becomes the curve at which the settlement is 20 mm and f_i is the maximum range of 170 to 210 kPa. The consolidation/ expansion of slag progresses and the slag is considered to become integral with the pile body at this stage.

On the other hand, the onset of consolidation and expansion of the slag below the groundwater level at a curing period of 3 months is delayed. As a result, the development of f_i for both kinds of slag is small, and no difference is observed in this value for all kinds of soil.

(d) Comparison of the shapes and kinds of precast concrete piles showed that for the same packing slag, the development of f_i for the straight pile was smaller than that of the nodular pile for all soil sections. Moreover, the increase in f_i due to reloading was only at the pile tip. At other sections, the same value or a reduced value was observed.

3.2 *On-site tests in ground with clayey soil*

3.2.1 *Test method*

Test piles were constructed mainly in ground with clayey soil by two construction methods: the bored and slag-packed piling method and the bored and cement milk-packed piling method (conventional method) for comparison purpose.

For both construction methods, the precast concrete nodular pile was used as the test pile and two kinds of slag, namely, steelmaking slag and mixed slag, were used as the material packed around the pile.
To study the change with time of the bearing capacity of each test pile, the vertical load tests were carried out for test piles cured for 1 month and for 3 months. Test piles were further added to examine the effects of loading history of piles being cured on R_{conv}. Table 8 shows the test conditions.

Table 8. Test conditions

Test No.	Method	Pile type	Material of a filler	Time of a load test	
				1month	3months
K1	Bored	Nodular pile φ440-300 t=60,l=11m	Mixed Slag	−	○
K2			Mixed Slag	○	○
K3			Steelmaking Slag	○	○
K4	Bored (soil cement)		Soil cement	○	○

3.2.2 *Test ground and locations of installation of test piles*

The test ground had thick layers of alluvial deposits. Up to a ground level of 5.5 m below the surface, the ground had alternate sandy layers with an N-value of about 5 and clayey layers with an N-value of about 2. Sandy layers of medium density with an N-value of 10-17 comprised the ground from a level of 5.5 m to 7.6 m below the surface. At depths below 7.6 m, the ground consisted of clayey layers with an N-value ranging from 2 to 5. The groundwater level was 4.0 m below the ground level.
The tip of the test pile was embedded in a clayey layer 10.5 m below ground level.
Fig. 11 shows the soil boring log of the test ground and the positions of strain gauges installed on the test pile. The strain gauges were installed at the interface of each layer and on the pile head and pile tip ends.

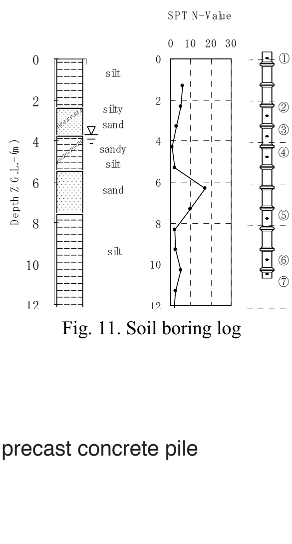


Fig. 11. Soil boring log

3.2.3 *Results of vertical loading tests and discussion*

(1) Results of measurement of pile head load and pile head settlement

Fig. 12 shows the Q versus S_h curve of each test pile according to the results of the vertical load tests. This Figure shows the Q versus S_h curves for curing periods of 1 month (bold line) and 3 months (broken line).

Table 9 shows the change with time of R_{conv} and the R_{conv} of each test pile.

(2) Results of measurement of strain in the pile

Fig. 13 shows the axial load distribution of each test pile and Fig. 14 shows the f_i versus S_i curve, based on the results of strain measurements of the pile. Fig. 15 shows the change with time of R_{conv}, R_p, and R_f.

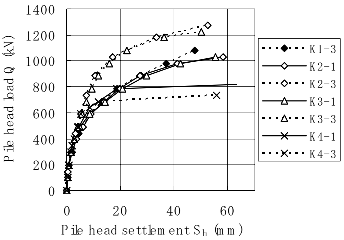


Fig. 12. Q～S_h interaction curve

Table 9. Change of R_{conv} with time

Conventional ultimate pile resistance R_{conv} (kN)			
Test No.	1month (a)	3months (b)	Ratio (b/a)
K1	-	1045	-
K2	989	1232	1.25
K3	988	1205	1.22
K4	785	723	0.92

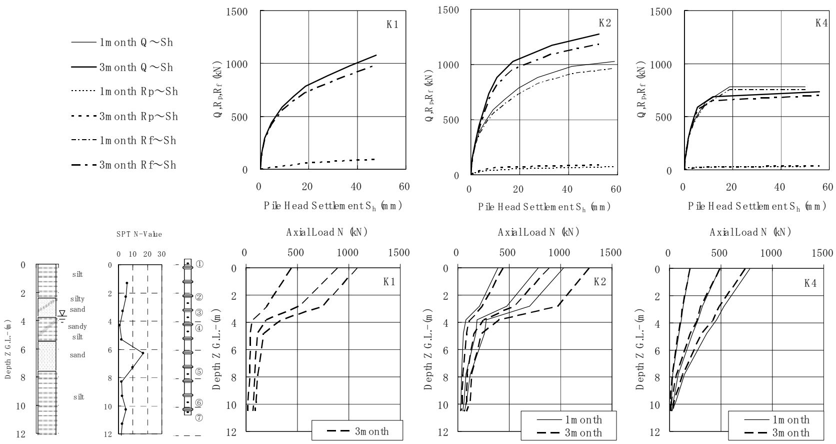


Fig. 13. Distribution map of axial load

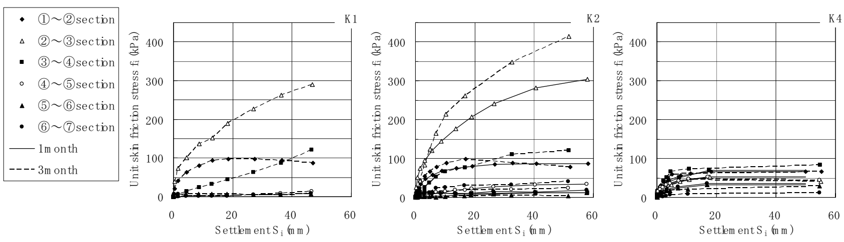


Fig. 14. f_i ~ S_i interaction curve at the section

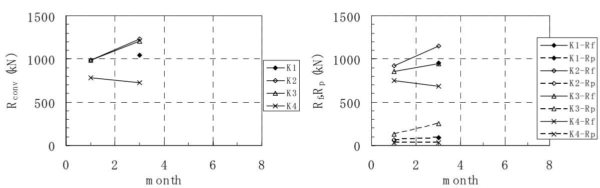


Fig. 15. Change of R_{conv},R_p,R_f with time

(3) Discussion based on the results

The following points regarding bearing capacity can be understood from the load-settlement relationship:

(a) By kind of packing slag, the bearing capacity of both kinds of slag at a curing period of 3 months was generally the same.

(b) Comparison of construction methods showed that the R_{conv} of the bored and slag-packed pile increased by approximately 1.3 times at a curing period of 1 month, and increased by approximately 1.8 times at a curing period of 3 months compared to the R_{conv} of the bored and cement milk-packed pile. The change with time of R_{conv} shows that during the reloading at a curing period of 3 months, the R_{conv} of the bored and slag-packed pile increased by about 1.2 times but that of the bored and cement milk-packed pile reduced to about 0.9 times.

From the distribution of axial loads and the f_i - S_i relationship, the following observations were made:

(c) Comparison of the different types of slag showed that the fi for the slag in the wet earth up to the groundwater level (4.0 m below ground level) appeared faster compared to the slag in earth in the saturated condition at depths below the groundwater level, and it accounted for 60% to 70% of the total resistance. Moreover, there was no difference in the development of f_i for both slags in clayey soil up to the ground water level, but in sandy soil, the f_i for mixed slag was about 1.9 times the f_i for the steelmaking slag. On the other hand, the onset of consolidation and expansion of both kinds of slag at depths larger than the groundwater level was delayed. Hence, the f_i at a curing period of 3 months was small, and no difference in f_i was observed for the different kinds of soil.

(d) Regardless of the kind of ground around the pile, the f_i value at a curing period of 1 month for the bored and cement milk-packed pile was uniform. In contrast, the value of f_i up to the groundwater level for the bored and slag-packed pile was 100 to 300 kPa, accounting for a major part of the total resistance. The settlement that occurred at the maximum value of f_i was about 10 mm in all the soil layers in case of the bored and cement milk-packed pile and the consolidated soil cement behaved as an integral part of the pile body. In contrast, in case of the bored and slag-packed pile, the settlement was greater than 50 mm in each layer at depths below the groundwater level. Therefore, the onset of consolidation and expansion of the slag was delayed.

(e) The R_{conv} of the bored and slag-packed pile reloaded at a curing period of 3 months increased to 1.25 times the R_{conv} at the initial loading. However, the R_{conv} of pile with no loading history at the curing period of 3 months was practically the same as the R_{conv} of pile with loading history at the initial loading stage. Therefore, the consolidation of packed layers due to the loading at the initial curing period is effective for the early development of bearing capacity.

3.3 *Tests on large soil chamber in sandy ground*

3.3.1 *Test method*

Various test piles were constructed by the bored and slag-packed piling method in sandy ground made of large soil chamber (length 6 m, width 4 m, depth 5 m).

The precast concrete nodular pile was used as the test pile and two kinds of slag, namely, steelmaking slag and mixed slag, were used as the material for packing the pile.

To study the change with time of the bearing capacity of each test pile, the vertical load tests were carried out for test piles cured for 1 month and for 3 months. Test piles were further added to examine the presence or absence of effects of loading history of piles being cured, on R_{conv}. Table 10 shows the test conditions.

Table 10. Test conditions

Test No.	Method	Pile type	Material of a filler	Time of a load test		
				1 month	3 months	6 months
Y1	Bored	Nodular pile φ440-300, t=60,l=4m	Mixed Slag	○	○	○
Y2			Mixed Slag	−	○	○
Y3			Steel-making Slag	○	○	○
Y4			Steel-making Slag	−	○	○

3.3.2 *Test ground and locations of installation of test piles*

Artificial fill ground is sandy ground of medium density with an N-value of about 20. After construction of the test piles, the sandy ground was considered to be in the saturated condition taking the groundwater level as the ground level (GL ±0 m).

The test pile was installed with its tip at 3.0 m below ground level in sandy ground.

Fig. 16 shows the soil boring log of the fill ground and the positions of installed strain gauges on the test pile. Strain gauges were installed in the pile head, center of the pile and pile tip ends.

3.3.3 *Results of vertical loading tests and discussion*

(1) Results of measurement of pile head load and pile head settlement

Fig. 17 shows the Q versus S_h curve of each test pile according to the results of the vertical load tests. This Figure shows the Q versus S_h curves for curing periods of 1 month (bold line) and 3 months (broken line) and 6 month (chain line).

Table 11 shows the R_{conv} of each test pile and the R_{conv} with the change in time.

(2) Results of measurement of strain in the pile

Fig. 18,19 shows the axial load distribution of each test pile and Fig. 20,21 shows the f_i versus S_i curve, based on the results of strain measurement of the pile. Fig. 22 shows the change with time of R_{conv}, R_p, and R_f.

(3) Discussion based on the results

Conclusions arrived at regarding the bearing capacity based on the results of Table 11 are as follows:

(a) Comparison of the various kinds of packing materials showed that the R_{conv} of bored and slag-packed pile in saturated sandy ground when mixed slag was used was about 1.4 times larger than the case when steel-making slag was used as packing material. With the change in time, the bearing capacity increased by about 1.5 to 2.0 times compared to the initial loading result for both kinds of slag when the pile was re-loaded at a curing period of 3 months and 6 months.

(b) The effects of the presence/absence of loading history during the curing period on the bearing capacity were studied. It was found that the R_{conv} of pile initially loaded at a curing period of 3 months was about 0.65 times (for mixed slag) and about 0.8 times (for steel-

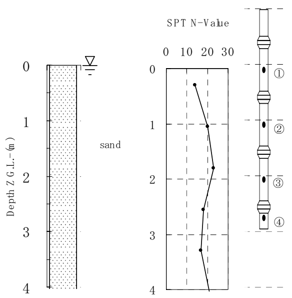


Fig. 16. Soil boring log

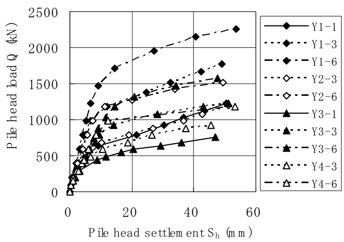


Fig. 17. Q～S_h interaction curve

Table 11. Change of R_{conv} with time

Conventional ultimate pile resistance R_{conv} (kN)					
Test No.	1month (a)	3months (b)	Ratio (b/a)	6months (c)	Ratio (c/a)
Y1	1135	1693	1.49	2182	1.29
Y2	-	1095	-	1487	1.36
Y3	737	1183	1.61	1542	1.30
Y4	-	920	-	1133	1.23

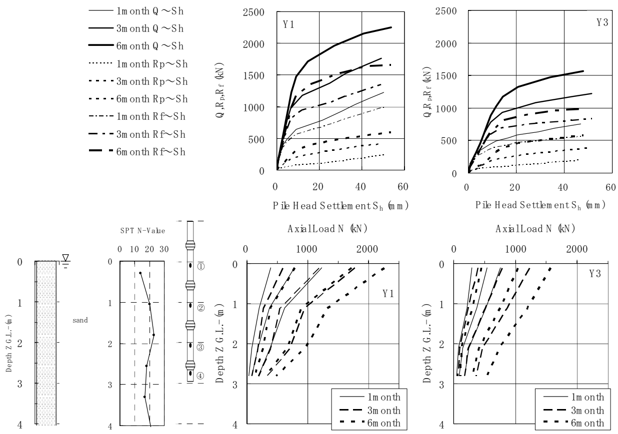


Fig. 18. Distribution map of axial load (Y1,Y3)

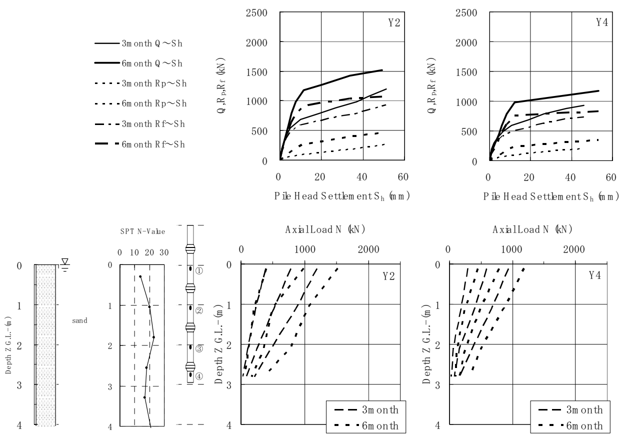


Fig. 19. Distribution map of axial load (Y2,Y4)

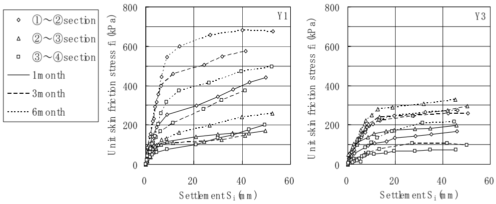


Fig. 20. $f_i \sim S_i$ interaction curve at the section (Y1,Y3)

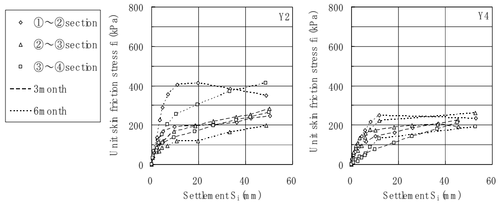


Fig. 21. $f_i \sim S_i$ interaction curve at the section (Y2,Y4)

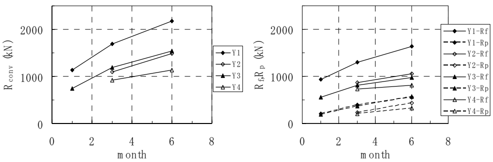


Fig. 22. Change of R_{conv},R_p,R_f with time

making slag) the bearing capacity compared to the R_{conv} of the pile with loading history when it was reloaded. Moreover, the R_{conv} was 0.96 times for mixed slag and about 1.25 times for steelmaking slag compared to the R_{conv} in the initial condition of the pile with loading history. This suggests that loading the pile in the initial stage of curing is effective in developing the bearing capacity of the pile at an early stage.

Next, the following conclusions were arrived at from the f_i - S_i relationship and the axial load distribution, based on the condition that the sandy ground was saturated with water:

(c) The development of f_i in case of mixed slag was more noticeable closer to the surface. In contrast, the development of f_i incase of steelmaking slag was almost uniform throughout the depth. The f_i for mixed slag at a curing period of 6 months was about 2 times the f_i for steelmaking slag on an average.

(d) During on-site tests in sandy soil and clayey soil, consolidation and expansion of the slag layers below the groundwater level were excessively delayed. In contrast, an increase in the bearing capacity due to consolidation of slag layers in water was verified in this test. This is because the outflow/inflow of groundwater occurred constantly in the on-site tests, whereas no outflow of water occurred from the large soil chambers in these tests. As a result, consolidation progressed due to the concentration of Ca ions that leached from the slag. Reaction layers were observed at the interface of the slag and the ground when the ground was excavated after the tests.

4 RELATIONSHIP BETWEEN SKIN FRICTION F_I OF THE BORED AND SLAG-PACKED PILE, TIP RESISTANCE Q_P AND N-VALUE

Regression equations were derived from the relationship between skin friction of the section, f_i, and the average N-value of the section at the conventional ultimate pile resistance R_{conv}, and the relationship between the pile tip resistance q_p and pile tip N_p. The sandy soil and clayey soil were assumed to account for more than 70% of the volume at each section, and the skin friction at the section and average N-value of the section were taken as f_s, N_s, f_c and N_c respectively. The N-value at the pile tip, N_p, was taken as the net average N-value in the range of "1 D_b above and 1 D_b below" the lowest node.

Fig. 23 and Fig. 24 show the f versus N relationship, while Fig. 25 shows the q_p versus N_p relationship.

From the above, the following conclusions were arrived at:

(1) In sandy ground, the f_s of pile reloaded at a curing period of 3 months increased to approximately 1.4 times the f_s at the initial loading condition. As curing progresses, the N-value of the surrounding ground was directly proportional to f_s.

(2) In clayey ground, the f_c of pile reloaded at a curing period of 3 months increased by 1.2 to 2.4 times the corresponding value at the initial loading test. However, in clayey layers below the groundwater layer during the curing period, f_c developed according to the action of the pile body and the coarse-grained slag and showed a constant value regardless of the N-value of the surrounding ground. After a long curing period, the packed slag becomes integral with the pile

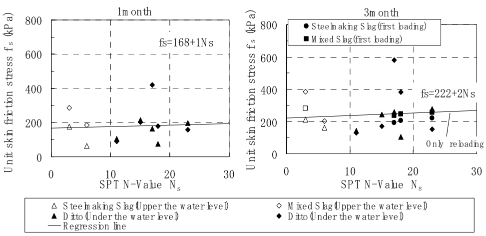


Fig. 23. Relation between f_s and N_s

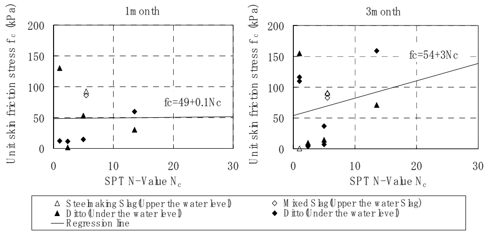


Fig. 24. Relation between f_c and N_c

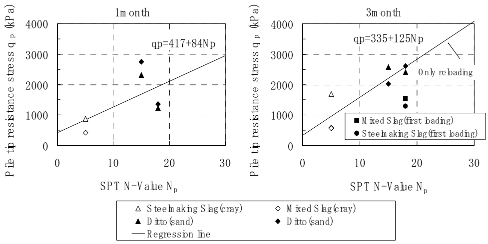


Fig. 25. Relation between q_p and N_p

body, resulting in a proportional relationship between the N-value of the surrounding ground and f_c.

(3) The pile tip resistance stress, q_p, of piles with loading history increased during reloading. This trend is similar to that of ordinary bored precast concrete piles. That is, q_p is the stress level that appears between the pile tip and the ground with the increase in the relative density of the ground due to the compression during penetration of the pile tip into the ground.

5 CONCLUSIONS

(1) By using Iron and steel slag as packing material in the bored precast concrete piling method, it was verified that the bearing capacity of the pile increases.

(2) The bored and slag-packed pile develops excellent bearing capacity compared to the bored and cement milk-packed pile constructed by the conventional method. Particularly, the bearing capacity increases remarkably with the passage of time to a level that cannot be obtained by conventional construction methods. Accordingly, the use of slag instead of soil cement enables reduction in costs and moreover, if such a bearing capacity at the completion of building structures can be used during design, then further cost benefits may be anticipated.

(3) By combining a precast concrete nodular pile with iron and steel slag, the bearing capacity of the part below the node can be increased and high bearing capacity can be developed.

(4) The bored and slag-packed pile is effective in sandy and clayey soils since the bearing capacity increases. The bearing capacity particularly in sandy ground is very high.

(5) The skin friction of bored and slag-packed pile develops faster in ground in the wet condition upper the groundwater level. However, in ground below the groundwater level, the onset of consolidation and expansion of the slag is delayed because of the inflow/outflow of water, and more time is necessary for the development of skin friction.

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