The Countermeasure for Press-in Method on Lengthy SPSPs and the Confirmation of the Bearing Capacity Obtained by Pile Loading Test

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ABSTRACT

A Steel pile sheet pile (SPSP) foundation on a viaduct construction site was designed and constructed using the press-in method combined with inner excavation. After driving the pile, the press-in method combined with inner excavation was not able to drive the piles into the ground to the required depth, so the press-in with water jetting method was adopted after considering environmental impact, economy, and work schedule. With the press-in with water jetting method, the pile was driven to the required penetration depth while water was pumped under high pressure through pipes internally attached to the pile. The press-in with water jetting method was selected as a piling method for the steel pipe sheet pile foundation which is adjacent to a river, a highway, and houses in a confined space. There has been no recommended bearing capacity formula for press-in with water jetting method in Japanese design specifications for highway bridges, so the information of the vertical resistance characteristics (end-bearing capacity, skin friction) and lateral resistance characteristics (modulus of horizontal subgrade reaction) of the foundation was determined by a loading test to obtain the properties of foundation after changing the pile driving method. Using chemical grouting to increase the ultimate bearing capacity is also discussed. According to the results of vertical loading test and horizontal loading test after ground improvement, the ultimate bearing capacity was confirmed to be greater than the designed value for Level 2 earthquake. The stress in the piles was confirmed to be smaller than the allowable value both for Level 1 and Level 2 earthquake. The Steel pipe sheet pile foundation using the press-in with water jetting method combined with the grouting method had full structural abilities for Pier structures.

Key words: *press-in with water jetting, pile loading test, frictional resistance, grouting*

1. Outline of the project

1.1. Place

The project involves the construction of approximately a 1.2 km long viaduct substructure (47 piers and 2 abutments) of Metropolitan Inter-City Expressway in Okegawa city (See **Fig. 1**, No.2 viaduct substructure construction).

1.2. Background and objectives of the project

The foundation of piers includes Sheet pile soil cement foundation(φ1200 L=10.0m~42.5m) and Steel pipe sheet pile (SPSP) foundation (φ800 L=15.5m~51.0m, the combination with temporary cofferdam). In this report, the construction of Steel pipe sheet pile foundation is carried out (See **Fig. 2**).

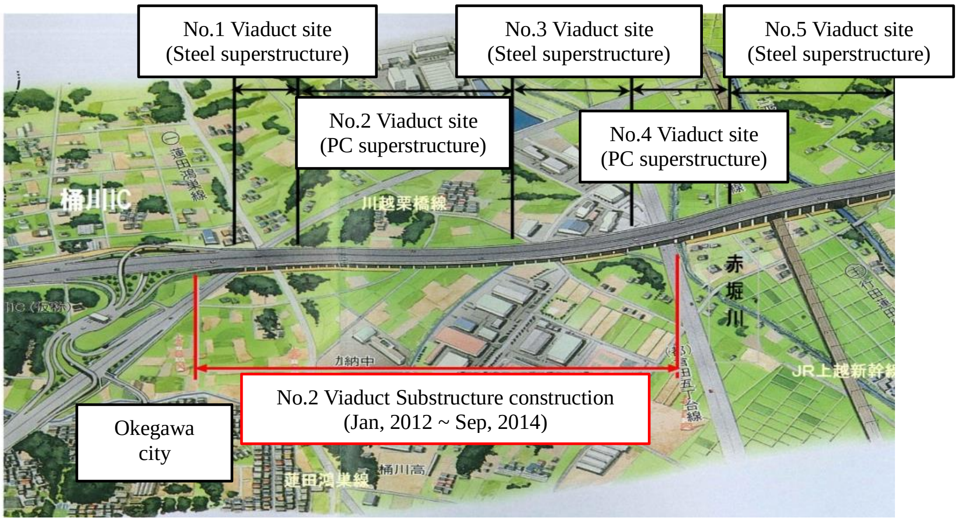

Fig. 1 The layout of the construction site

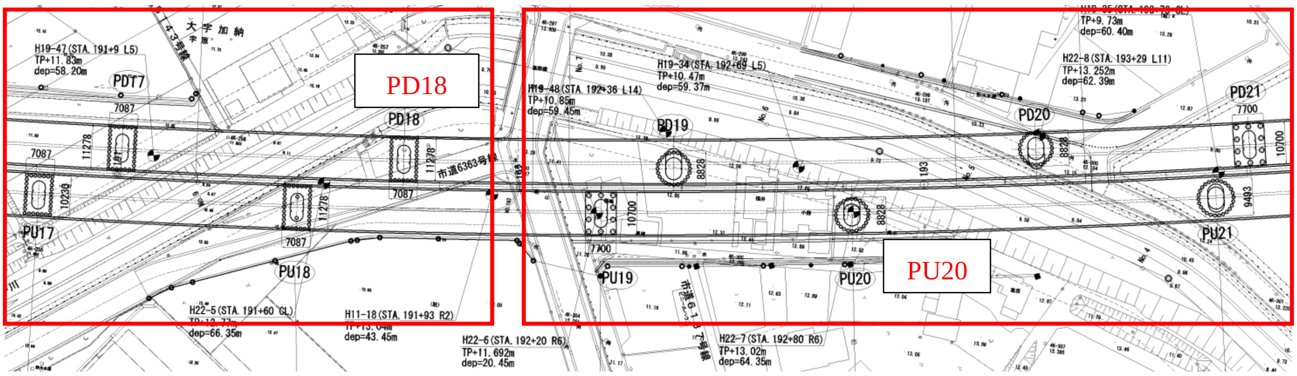

Fig. 2 The layout of Steel pipe sheet pile foundations

The SPSPs were installed using the press-in method combined with inner excavation (press-in forces 800kN, inner excavation with tip enlarged foot protection method) in the original design. The numbers and the lengths of SPSPs are shown in **Table 1**. A total of 4 SPSP foundations using the 15.5m length of SPSPs (See **Fig. 2**) were installed completely by using the press-in method combined with inner excavation. However, with regards to the 51.0m length of piles (PU20 Pier (See **Fig. 3**)), the press-in method combined with inner excavation was not able to drive SPSP into the ground to the required depth during the construction of the first long SPSP. This is because the friction between piles and clay soil increased with the penetration of piles. In the first countermeasure, the hydraulic vibratory pile hammer (vibration force 473kN) and the electric vibratory pile hammer (vibration force 568kN) were used to penetrate the pile into the bearing layer. However, they did not work well.

Table 1. Number and length of SPSPs

Pier No.	SPSP length (m)	Number of pile
PU17	15.5	30
PD17	15.5	32
PU18	15.5	32
PD18	15.5	32
PD19	49.5	24
PU20	51.0	24
PD20	49.5	24
PU21	47.5	26

The press-in with water jetting method was adopted instead. There has been no recommended bearing capacity formula for press-in with water jetting method in Japanese design specifications for highway bridges. Therefore, the confirmation of the bearing capacity by pile loading test was conducted.

2. Site condition

2.1. Site condition

The construction site is adjacent to a residential area

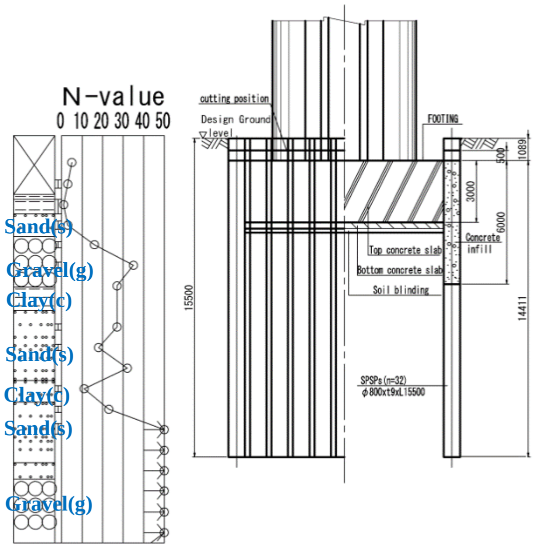

Fig. 3 Soil boring log and SPSP foundation of PD18 Pier

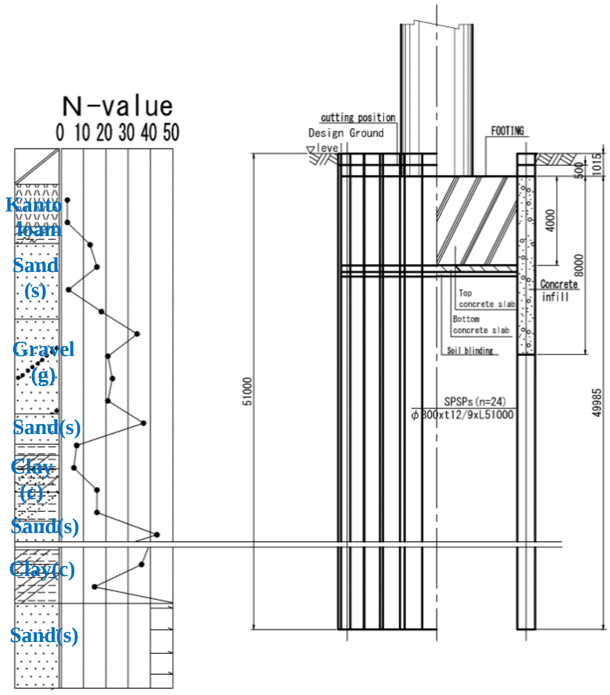

Fig. 4 Soil boring log and SPSP foundation of PU20 Pier

Fig. 5 Press-in with water jetting method

Fig. 6 The retention basin

and a precision machine tool plant, therefore environmentally friendly methods such as those with less noise and less vibration must be applied. In addition, the available time allocated to the main road was limited, and it was difficult to modify the schedule. For the above reasons, the press-in with water jetting method using press-in forces 2600 kN of a press-in machine was adopted to drive pile to the required depth instead of changing to other methods like caisson foundation or pile foundation.

2.2. Ground condition

Soil description and Standard Penetration Test (SPT) are shown in **Fig. 3**, and **Fig. 4**. The penetration depth of PSPSs is planned to locate mainly in the stiff sand layer where N value is larger than 50.

3. Press-in piling

3.1. Layout

A photo of typical press-in with water jetting method is shown in **Fig. 5**.

3.2. Wastewater treatment

The force applied using the Press-in machine was 2600 kN. A total of 4 water jetting machines (AT330ES V) with maximum recharge of 900 l/min capacity were used to supply water which was taken from the adjacent river.

As for the water treatment, wastewater during construction was transferred to a retention basin approximately 200 m away from the site with appropriate authority without a mechanical process. In the retention basin, a sandbag weir was constructed to prevent waste soil from entering the river and allow the supernatant to flow to the river when the water level is higher than the weir height (See **Fig. 6**).

3.3. Piling process

With the press-in with water jetting method, the pile is driven to the required penetration depth while the water is pumped under high pressure through pipes internally attached to the pile. At the same time, water flow reduces skin friction of pile and reduces interlock resistance by washing out soil inside the interlock. There has been no recommended bearing capacity formula for press-in with water jetting method in Japanese design specifications for highway bridges, so the information of the vertical resistance characteristics (end-bearing capacity, skin friction) and lateral resistance characteristics (modulus of horizontal subgrade reaction) of the foundation was determined by a loading test to obtain the properties of foundation after changing the pile driving method.

The test flow is shown in **Fig. 7**. After confirming the bearing capacity of the test pile, the press-in method was conducted without chemical grouting. Otherwise, the chemical grouting will be used to increase the ultimate bearing capacity. After grouting, the loading test will be used for proof of bearing capacity working on the pile.

The driving of PU20 Pier with sheet pile 51.0 m long using the press-in with water jetting was used to determine the test flow.

4. Results

4.1. The press-in with water jetting

Sheet piles with lengths from 47.5 m to 51.0 m of 4 Piers were successfully driven using the press-in with water jetting.

During construction, the noise level did not exceed 75dB consistent with the noise regulation standards, improved environmental conditions. Because the supernatant was allowed to flow into the river, the level of suspended solids (SS) was measured 2 times per day during construction of SPSPs to determine the characteristics of the municipal wastewater. The result shows that SS did not exceed the wastewater effluent limit of 180 mg/L.

The driving of the SPSPs was from 0.5 to 0.7 pile/day in the initial planning with the press-in method combined with inner excavation. There are no differences between two press-in methods of driving time so there was no negative impact on the use duration of the main road.

Fig. 8 shows the construction conditions during driving and after driving the pile.

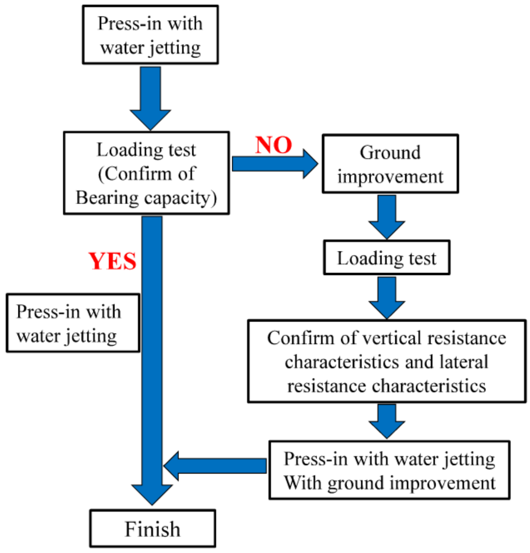

Fig. 7 The Test flow

Fig. 8 The view of site during and after the

4.2. Pile loading test (Before ground improvement)

Strain gauges (32 points of 16 cross-sections into 2 directions), displacement gauges (installed in the pile tip) and multi-layer inclinometer (10 points in 10 cross sections) were installed to measure the displacement of test pile during driving to the required depth (See **Fig. 9**).

The capacity of the test equipment was 8000 kN. The test equipment consists of 2 load beams (1700 mm×450 mm), 4 load transfer beams (864 mm×750 mm), 8 reaction piles (See **Fig. 10**). The location of reaction piles and test pile of loading test was carried out with respect to Japanese design specifications for highway bridges.

A vertical loading test on the pile was conducted 14 days after driving pile by using the press-in with water jetting method in order to ensure the recovery of frictional resistance. The curing period (14 days) was determined in accordance with [JGS 1811-2002] and the limit of the original schedule. In addition, the SPSPs wall did not prevent the dissipation of excess porewater pressure because the interlocked joints are typically permeable, which allows leakage through these joints (The interlocked joint of the SPSPs filled by mortar after the loading test). The results of the vertical loading test are shown in **Fig. 11**. When the load test was 2400 kN, the end-bearing capacity value was 1767 kN which was similar to the value of the method of installing piles by inner excavation combined with final strike method (1764 kN) calculated by the formula of Japanese design specifications for highway bridges. In addition, the end-bearing capacity, skin friction and ultimate bearing capacity of pile using inner excavation combined with the pressure feed of cement milk method in the original

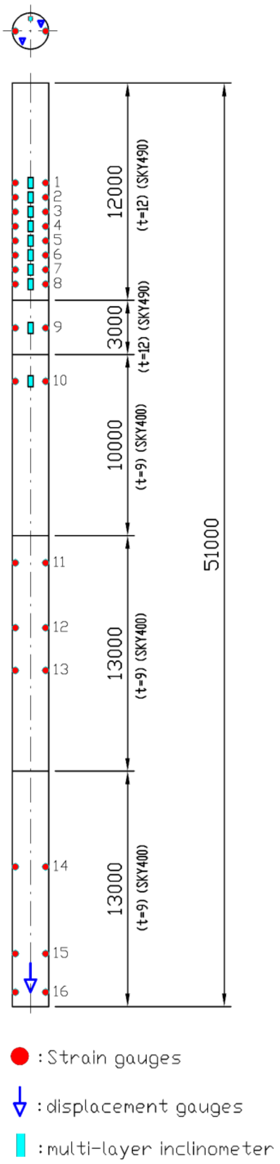

Fig. 9 Outline of the gauges

Fig. 10 Vertical pile loading test

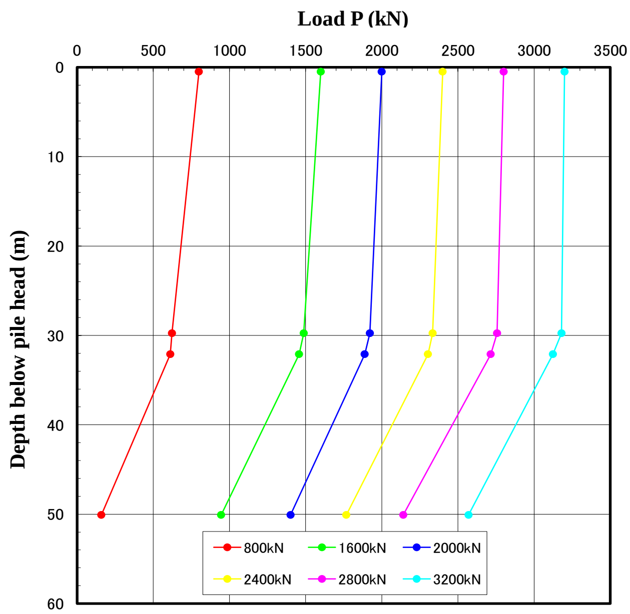

Fig. 11 Relationship between load test and depth below pile head

design was 3544 kN, 4275 kN and 7819 kN, respectively (See **Table 3,** calculated by the formula of Japanese design specifications for highway bridges).

Design skin friction was calculated for the condition to ensure that the foundation failure will not occur in a Level 2 earthquake. The test skin friction capacity (632 kN) was less than design skin friction (2470 kN).

The load test was 3200 kN although the planned maximum test load was 8000 kN (See **Fig. 11**). So the chemical grouting method with permanent grout material was used to increase frictional resistance of piles.

4.3. Ground improvement

4.3.1. Grouting method

A process of injecting grout under pressure into the interface between the exterior of the shaft and the surrounding soil after completion of driving SPSPs was planned to increase the skin friction capacity.

Comparing with other methods of ground improvement such as chemical grouting method (dual-tube double-packer method) and jet grouting method, the dual-tube method has no problem with deep ground improvement and able to obtain the strength of permanent grout material. In addition, the dual-tube method was more economical. As a result, the dual-tube method was adopted.

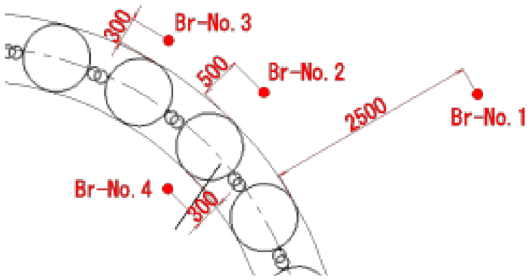

Fig. 12 Extra Boring position

4.3.2. Design

A total of 4 extra borings were conducted at the nearing sheet pile to evaluate the property construction range limit of grouting in advance (See **Fig. 12**). Three borings were outside the cofferdam with the distance 0.3 m (Br-No.3), 0.5 m (Br-No.2), 2.5 m (Br-No.1) respectively and another one was inside with the distance 0.3 m (Br-No.4).

Based on the data from the original boring and extra boring, the soil strata and N value were determined to evaluate the effective bound of grouting (See **Table 2**). In the same sand layer, the N value of Br-No.3 was less than other borings results. There was no difference between N value of borings in the loam, clay soil layer. As a result, grout is injected at the points which are 0.3 m outside the cofferdam (See **Fig. 13**). Therefore, grouting was set outside the cofferdam and injected from pile head to toe level based on the structural design of the cofferdam.

Table 2. Boring data

Soil Type	N value			
	Original boring	Br-No.1	Br-No.2	Br-No.3
Loam	3.0	2.7	2.5	3.5
Sand	12.3	18.7	16.4	12.0
Gravel	24.8	23.8	16.3	12.8
Sand	37.0	21.5	35.0	24.0
Clay	11.3	10.3	7.3	12.3
Sand	28.3	32.2	34.3	22.6
Sand	23.6	29.8	28.7	18.0
Clay	10.0	9.0	7.7	5.7
Sand	54.0	52.5	35.0	17.8
Clay	25.0	25.7	26.0	19.7
Sand	36.0	47.5	60.0	20.0
Clay	14.0	20.2	25.8	11.4

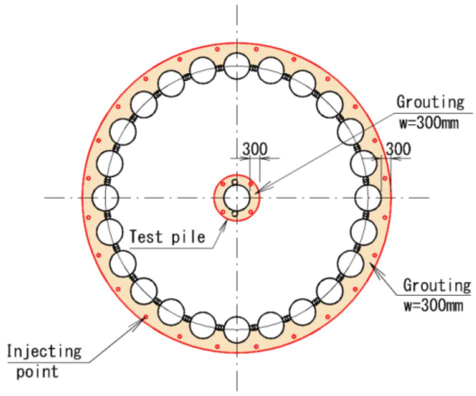

Fig. 13 Ground Improvement

4.3.3. Grouting

After completion of driving SPSPs, grouting was taken for 4 tabular foundations.

4.3.3.1. Boring

Because grout is injected at the points which are 0.3 m outside the cofferdam, borehole will be made 0.15m outside the foundation similar to a number of the pile by using 2 rotary packer drill machines (See **Fig. 14**).

4.3.3.2. Injecting

The injection of permanent grout material was

Fig. 14 Boring apparatus

Fig. 15 Injecting apparatus

conducted using 8 machines of grout injection pump. In order to control pressure balancing on the pile, SPSPs foundation was divided into 8 parts (3 piles/part), and the grout was injected at a staggered arrangement to ensure that the adjacent points are not injected at the same time (See **Fig. 15**).

Eight grout injection pumps were used at the same time at 8 parts to avoid gradual injection pressure and prevent the escape of grout.

Table 3. Results of loading test

	End-bearing capacity (kN)	Skin friction (kN)	Ultimate bearing capacity (kN)
Original Design(1)	3544	4275	7819
Before grouting(2)	1767	632	2399
After grouting(2)	—	—	>8800(3)

(1) Inner excavation combined with the pressure feed of cement milk method (Level 2 earthquake); Design value for Level 1 earthquake was half of its value for Level 2
(2) Press-in with water jetting method
(3) Consist almost entirely of skin friction (see **Fig. 16**); the ultimate bearing capacity was greater than 8800 kN

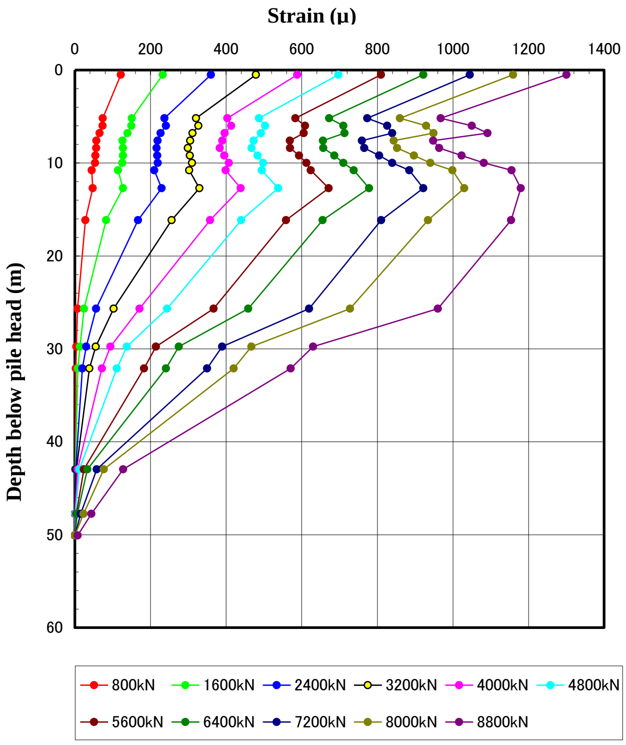

Fig. 16 Relationship between strain and depth below pile head

4.3.4. Pile loading test (After ground improvement)

4.3.4.1. Vertical loading test

After 28 days of grouting, vertical loading test was conducted to confirm the bearing capacity of test pile. In **Fig. 16** when the load test was 8800 kN, the displacement at the pile toe was less than 10% of the pile toe diameter. So the second-limit-resistance was greater than load test (8800 kN) and its original design value (7819 kN).

The skin friction capacity after completion of grouting was similar to its value of original design using press-in method combined with inner excavation.

4.3.4.2. Horizontal loading test

After excavation and leveling work inside the cofferdam, a horizontal loading test was conducted. The horizontal loading test was made by pushing three piles together during loading to measure horizontal displacement which was planned to be larger than 15 mm (See **Fig. 17**).

After obtaining the load-deflection data during loading test, the modulus of horizontal subgrade reaction was

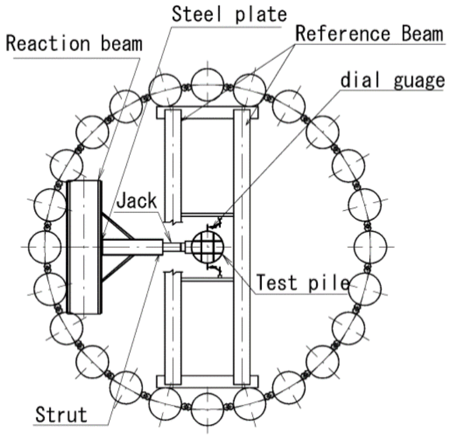

Fig. 17 Horizontal loading test setting

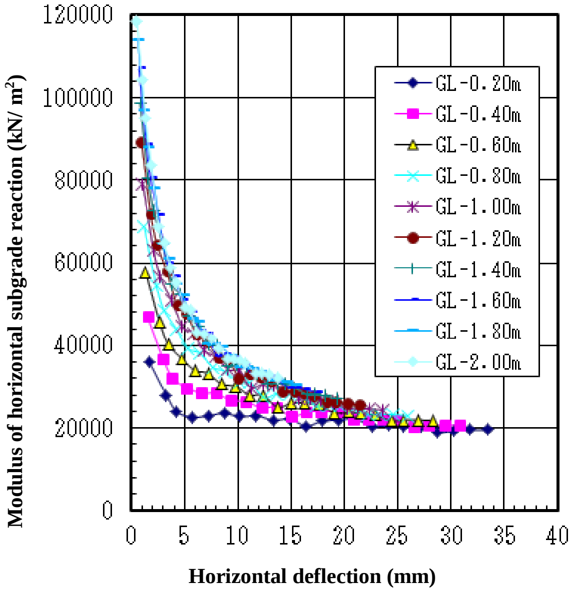

Fig. 18 Relationship between modulus of horizontal subgrade reaction and horizontal deflection

calculated as shown in **Fig. 18**. The coefficient of horizontal subgrade reaction obtained by horizontal loading test after grouting was similar to its value of original design. The ultimate bearing capacity was confirmed to be greater than the design value for Level 2 earthquake. The stress in the piles was confirmed to be smaller than the allowable value both for Level 1 and Level 2 earthquake.

According to the results of vertical loading test and horizontal loading test after ground improvement, the Steel pipe sheet pile foundation using the press-in with water jetting method combined with grouting method had full structural abilities for Pier structures.

5. Conclusion

In this report, the press-in with water jetting method was determined based on the steel pipe sheet pile foundation in order to solve the problem in construction. The loading test was conducted to clarify the effects of this method and to confirm the bearing capacity before and after taking countermeasures using the chemical grouting method. The main conclusions are outlined below.

(1) After using the press-in with water jetting method, the reduction of skin friction was confirmed by using vertical loading test.

(2) The skin friction capacity after completion of grouting was similar to its value of original design using the press-in method combined with inner excavation.

(3) The coefficient of horizontal subgrade reaction obtained by horizontal loading test after grouting was similar to its value of original design. It was the same level in comparison with the original ground.

(4) According to the results of vertical loading test and horizontal loading test after ground improvement, the ultimate bearing capacity was confirmed to be greater than the design value for Level 2 earthquake. The stress in the piles was confirmed to be smaller than the allowable value both for Level 1 and Level 2 earthquake.

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