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Preliminary results of questionnaire survey on field performance of press-in machine

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ABSTRACT: Field performance of press-in piling greatly depends both on performance of machine and on operators' experiences and skills. A questionnaire survey was conducted on the field performance of press-in piling machine, with the special attention to Gyro Piler. The paper firstly describes key maintenance items of the piling machine for effective piling operation provided by the manufacture. The items listed are a good indication of the parts of machine that may experience malfunction when operators use the machine in a way that mechanical design engineers do not expect. The paper secondly describes the objectives, the methods and results of the questionnaire survey. The survey concludes that operator's experience and skill play an important role for effective press-in piling with a minimum risk for damaging the machine.

1 INTRODUCTION

Modern construction project is performed by a collective and integrated effort of design engineers, construction machinery and its operators on site. It is particularly true for successful press-in piling. Design engineers must select an appropriate piling machine based on the information of soil profiles, construction environments and required performance of piles to be installed. Performance of the final product of piles installed largely depends on the skill of the operator with a proper handling of the machine (Bolton et al., 2020).

It is also of vital importance that the machine used on site must be well maintained for achieving the required performance of piles installed.

Unproper selection of machine and misuse of the machine may lead to disruption or suspension of operations, resulting in delay of the piling project and may even result in damage of the piling machine.

Effective piling operation can only be achieved both by a good combination of a well-maintained machine and a skillful operator.

This paper tries to find out the role of skill and experience of the operator on effective piling with less damage of piling machine by a questionnaire survey.

2 MACHINE MAINTENANCE

Every machine needs a regular maintenance to make a full use of its capability. It is a common practice that manufacturers provide a maintenance service program as well as a user's manual for customers. The manufacturer of press-in piling machine also follows the same practice mentioned above, offering the user's manual and a maintenance system covering over the period of their intended service life.

Fundamental maintenance items are a good indication of the essential parts of the machine necessary for normal effective operation, which in turn infers the parts that may experience malfunction when operators misuse the machine in a way that mechanical design engineers do not expect.

As was pointed out earlier, any machine breakdown may lead to suspension of the piling operation, resulting in delay of the project. Misuse of the machine by the unexperienced operator may lead to failure of the machine.

Key maintenance items for ordinary press-in machine that the manufacture lists up include (1) proper clearance (adjustment): clump, chuck, leader mast, (2) teeth (replacement when excessive wear): at chuck, (3) replacement of packing: main cylinders, hydraulic hoses, (4) replace hanging wires: wire for main body, for power unit (GIKEN, 2019).

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Figure 1 Illustrates the parts for the key maintenance items.

Validity of the disclaimer states, in most cases, that the maintenance insurance coverage excludes when operators use the machine, violating the user's manual that the manufacturer provides. It is, therefore, the key for effective piling to foster skillful operators with adequate knowledge of press-in piling and experiences on site.

3 QUESTIONNAIRE SURVEY

3.1 *Objectives*

This survey aimed at identifying how experienced operators select various driving setting values, and which press-in indices they consider important, depending on a given soil profile and a given piling project. This survey also tried to find out the differences of these setting values between experienced and less experienced operators.

3.2 *Method of survey*

A questionnaire survey was adopted in this investigation. In this survey Gyro Piler (Gyropress Method) was selected as a target machine among a family of press-in piling machines.

The first-round survey was conducted during the period of April, 2020 to May, 2020 to examine the feasibility of the questionnaire items. Based on the results of the first-round survey, the items of questionnaire were reviewed and modified. The second-round survey was then conducted during the period of May,2020 to June, 2020. Supplementally, some respondents were interviewed to clarify their answers.

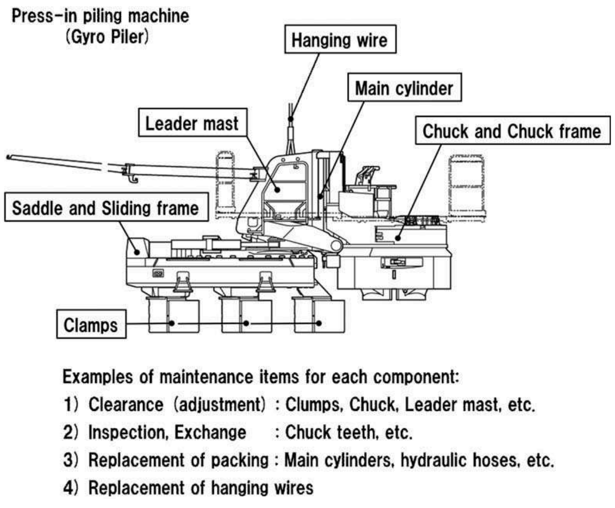

Figure 1. Key parts for regular maintenance.

3.3 *Gyropress method (Rotary Press-in Piling)*

As shown in Figure 2, the rotary press-in piling is a technology that installs steel tubular piles by rotating a pile with pile toe ring bits. To reduce rotary press-in resistance, the rotary press-in piling operation uses additional driving assistances such as water supply with a water lubrication system (LS) and air supply with an air system.

The water lubrication system discharges a small water with a discharge rate of 10 to 60 ℓ/min to reduce frictional resistance between a steel tubular pile and ground. Figure 3 shows the configuration of equipment for the rotary press-in piling, while Figures 4 and 5 show water discharge and the specifications of the water lubrication system, respectively. The number of water supply pipes and the water flow rate per pipe (also, the total water flow rate) are to be selected by each operator, considering soil profile and types of pile to be installed.

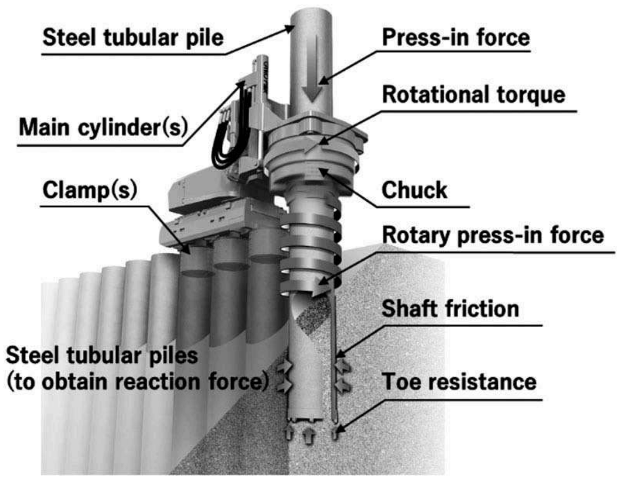

Figure 2. Conceptual diagram of rotary press-in piling.

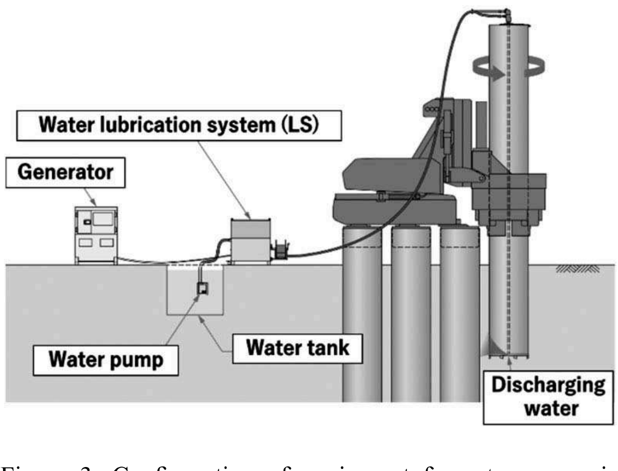

Figure 3. Configuration of equipment for rotary press-in piling.

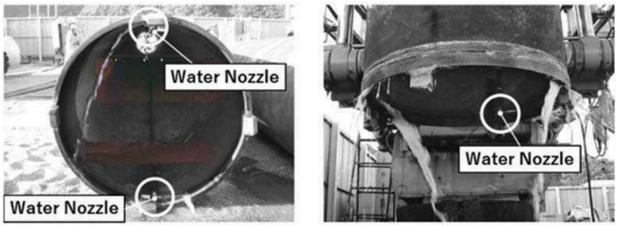

Figure 4. Water discharge using the water lubrication system.

Water Lubrication System (LS)	Specification
Water pump discharge rate	Max. 60 ℓ /min
Water pump discharge pressure	Max. 6 MPa
Water tank capacity	300 ℓ

Figure 5. Specification of the water lubrication system.

3.4 *Questionnaire items*

The survey aimed at identifying how experienced operators select key press-in parameters which would affect effective piling operation, depending on the type of soil profile and on the diameter of steel tubular pile. 21m long piles were assumed to be installed at 20m embedment. Figure 6 presents the referenced soil profiles for this survey, covering from soft clayey ground to stiff mudstone ground as below:

- Case 1. Silt/Loam, The SPT *N*-values: 10 to 30
- Case 2. Sand, The SPT *N*-values: 10 to 40
- Case 3. Gravels, The extrapolated SPT *N*-values: 50 to 150
- Case 4. Mudstone, The extrapolated SPT *N*-values: 50 to 150

The selected outside diameters of the pile were 800, 1000, and 1500mm. Available press-in piling machines designated for each diameter pile were listed in Table 1 with their specifications, such as speed of press-in/extraction and maximum torque.

Respondents were then asked to answer their choices of (1) machine, (2) the number of water supply pipes and their locations, and (3) initial setting values of press-in parameters. The value of press-in parameters includes press-in/extraction force, press-in/extraction speed, press-in/extraction stroke, and rotational torque/velocity of chuck. When water lubrication system(s) were used, the water flow rate is also an item of operator's choice. In the initial setting, three items are selected among given modes as below:

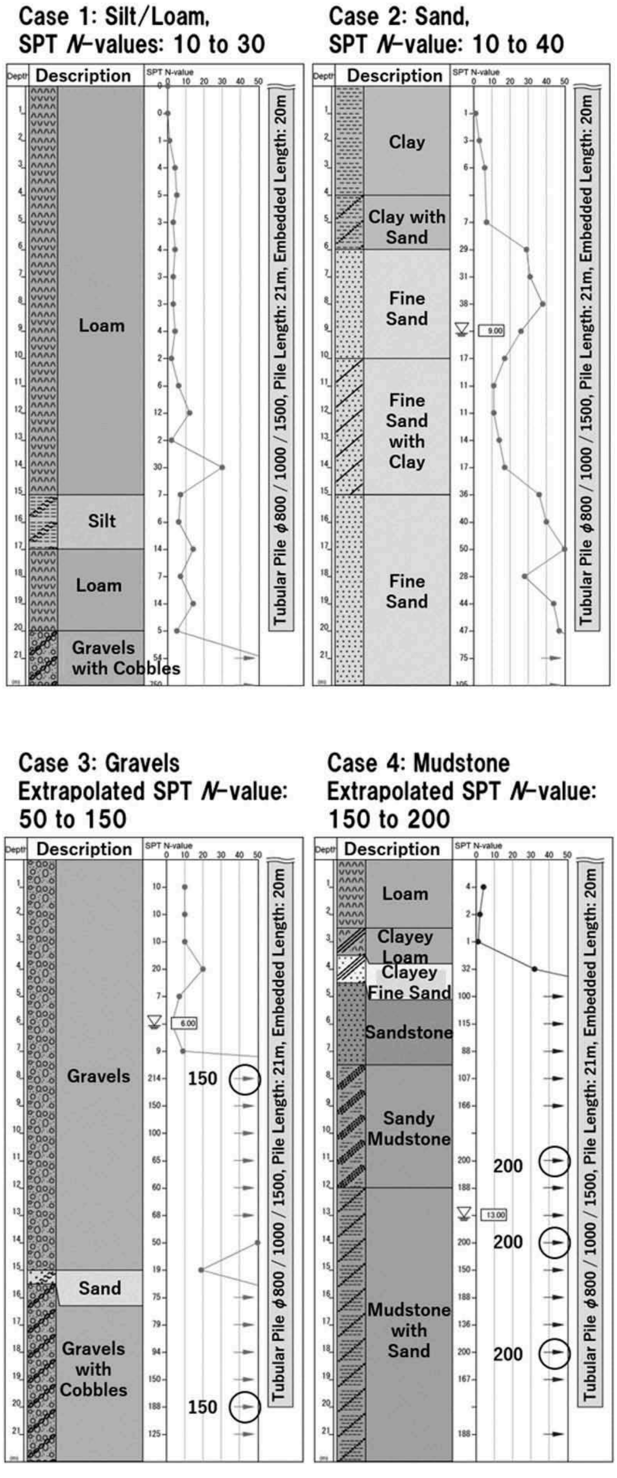

Figure 6. Referenced borehole logs: Case 1, 2, 3 and 4.

- Press-in Speed (m/s): mode 1 (Slow) to mode 5 (Fast) for F301 and F401, mode 1 (Slow) to mode 4 (Fast) for SP8
- Extraction Speed (m/s): mode 0 (Slow) to mode 5 (Fast) for F301 and F401, mode 0 (Slow) to mode 4 (Fast) for SP8
- Chuck Rotational Velocity (min^{-1}): mode 1 (Slow) to mode 5 (Fast) for F301, mode 0 (Slow) to mode 5 (Fast) for F401, mode 1 (Slow) to mode 6 (Fast) for SP8

Table 1. Available machines and their specifications.

Gyro-Piler	F301	F401	SP8
Applicable Diameters of Steel Tubular Piles	ϕ600-1000 mm	ϕ800-1200 mm	ϕ1200-1500 mm
Max. Press-in Force	700 kN	1500 kN	2000 kN
Max. Extraction Force	800 kN	1600 kN	2100 kN
Press-in Speed	0.005-4.3 m/min	0.002-4.9 m/min	0.002-2.0 m/min
Extraction Speed	1.4-8.7 m/min	0.7-3.5 m/min	0.4-3.4 m/min
Chuck Rotational Torque	600 kN·m	900 kN·m	1300 kN·m
Chuck Rotational Velocity	1.0 - 10.0 min^{-1}	1.5 - 11.0 min^{-1}	1.5 - 8.0 min^{-1}
Mass	17,800 kg (ϕ800)	32,600 kg (ϕ1000)	41,650 kg (ϕ1500)

Table 2. Example of a sheet of questionnaire.

	Case X (1~4)		A B C D		O
Machine / Material	Machine Model		F301/F401/SP8		
	Pile Diameter	mm	ϕ800/1000/1500		
	Pile Thickness	mm	9/12/16		
	Embedded Length	m	20		
	Lubrication System	unit			
	Water Supply Pipe	–			
	Pile Toe Ring Bits	–			
Initial Setting	Press-in Force	×10kN		•••	
	Press-in Speed	mode			
	Extraction Speed	mode			
	Press-in Stroke	mm			
	Extraction Stroke	mm			
	Water Flow Rate per Pipe	ℓ/min			
	Total Water Flow Rate	ℓ/min			
	Chuck Rotational Torque	kN · m			
	Chuck Rotational Velocity	mode			
	Remark	–			

3.5 *Respondents*

15 operators were selected from a piling company and were asked to fill in their answers in the sheet of questionnaire. Table 3 lists their years of experience of press-in machines and those of Gyro-piler.

4 RESULTS

4.1 *Survey results*

Table 4 shows a selected summary of the survey results for the soil profile, Case 1.

The results were examined from three aspects, namely influence of type of soil profile, influence of pile diameter and influence of operator's experience. The mean value and the standard deviation, the coefficient of variation (COV) were calculated for all the cases.

Table 3. Respondents and their experience.

Unit : year

Operator	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Experience of press-in piling machinery	22	10	20	27	26	6	20	25	29	28	8	5	4	9	4
Experience of Gyro Piler	12	5	5	9	5	4	4	10	7	7	3	2	2	4	2

Table 4. Summary of the survey (Soil Profile: Case1).

	Case 1 ; Silt / Loam, The SPT N-values are 0-30		A	G	I	M
Machine / Material	Machine Model	–	F301 / F401	F401	F401	F401
	Pile Diameter	mm	ϕ1000	ϕ1000	ϕ1000	ϕ1000
	Pile Thickness	mm	12	12	–	12
	Embedded Length	m	20	20	–	20
	Lubrication System	unit	1	1	2	2
	Water Supply Pipe	–	1	1	2	2
	Pile Toe Ring Bits	–	Standard	Standard	Standard	Standard
Initial Setting	Press-in Force	×10kN	20~30	40	25	20
	Press-in Speed	mode	Max.5	2	4	1
	Extraction Speed	mode	6	4	6	2
	Press-in Stroke	mm	800	300	140	300
	Extraction Stroke	mm	200	80	70	150
	Water Flow Rate per Pipe	ℓ/min	40	15	40	each 20
	Total Water Flow Rate	ℓ/min	40	15	80	40
	Chuck Rotational Torque	kN · m	250-280	250	200	200
	Chuck Rotational Velocity	mode	5	6	3~5	4
	Remark	–	A	–	–	–

Table 5 presents the summary of the statistical indices, including the maximum/minimum value, the mean (m), the standard deviation (σ), and the coefficient of variation (COV). From the table, it is noticed that most operators tend to select much less press-in force than the allowable maximum press-in force of the machine regardless of the ground stiffness and steel tubular pile diameter. This is one of noteworthy operator's tendencies observed in this study.

The following points are noticed from the preliminary results.

4.1.1 *Influence of type of soil profile*

Figure 7 shows the mean values of the selected press-in stroke plotted against the maximum SPT *N*-values for four different soil profiles for the case of the pile dimeter of 1,000mm. It is seen that there is a variation of the values of operator's selection. However, when excluding a few points far away from the other data, it appears that there is a tendency that the mean values of selected press-in stroke decrease with an increase of maximum SPT *N*-value. In the figure, three regression lines are drawn for reference. The solid line is all the selected data, the broken line is obtained from the data of the Group A, and the dotted line is obtained from the data of the Group B. These Groups were categorized by operator's experience. The definition of grouping will be described later in 4.1.3.

Figure 8 is the plots of the values of the mean value of selected total water flow rate versus the maximum SPT *N*-values for four different soil profiles, showing the trend that the total water flow rate is increasing as the stiffness of ground increases.

Some other tendencies can be pointed out.

- The mean values of selected press-in speed are lower, as the ground becomes stiffer.
- The mean value of the selected press-in stroke is decreasing as the ground stiffness increases, accordingly the mean value of extraction stroke follows the same trend. This means that the number of repetitive upward and downward motion (surging) is increasing as the ground stiffness increases.

Table 5. The summary of the statistical indices, including the maximum/minimum, the mean (m), the standard deviation (σ), and the coefficient of variation (COV).

Case1. Silt / Loam	The SPT *N*-values: 10-30		Pile Diameter φ800					Pile Diameter φ1000					Pile Diameter φ1500				
			Min.	Max.	Mean	Standard Deviation	Coefficient of Variation	Min.	Max.	Mean	Standard Deviation	Coefficient of Variation	Min.	Max.	Mean	Standard Deviation	Coefficient of Variation
			—	—	(m)	(σ)	(COV)	—	—	(m)	(σ)	(COV)	—	—	(m)	(σ)	(COV)
Machine / Material	Machine Model	–	F301/F401	F301/F401	—	—	—	F401	F401	—	—	—	SP8	SP8	—	—	—
Machine / Material	Pile Diameter	mm	800	800	—	—	—	1000	1000	—	—	—	1500	1500	—	—	—
Machine / Material	Pile Thickness	mm	9	9	—	—	—	12	12	—	—	—	16	16	—	—	—
Machine / Material	Embedded Length	m	20	20	—	—	—	20	20	—	—	—	20	20	—	—	—
Machine / Material	Lubrication System	unit	1	1.5	1.05	0.15	0.14	1	2	2	0.36	0.18	1.5	3	2.17	0.44	0.2
Machine / Material	Water Supply Pipe	–	1	2.5	1.14	0.45	0.39	1	2.5	2	0.39	0.20	2	3	2.25	0.4	0.18
Machine / Material	Pile Toe Ring Bits	–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Initial Setting	Press-in Force	×10kN	11	40	22	8.13	0.37	11	40	20	7.91	0.40	13.5	40	23	7.71	0.34
Initial Setting	Press-in Speed	mode	1	5	2.8	1.38	0.49	1	5	3	1.31	0.44	1	5	2.5	1.43	0.57
Initial Setting	Extraction Speed	mode	2	6	4.65	1.42	0.31	1.5	6	4	1.60	0.40	1.5	6	4.25	1.62	0.38
Initial Setting	Press-in Stroke	mm	140	1000	402	288.8	0.72	100	1000	406	288.8	0.71	140	1000	379.1	284.3	0.75
Initial Setting	Extraction Stroke	mm	50	200	104.5	53.6	0.51	50	200	110	48.6	0.44	50	200	104.5	50.9	0.49
Initial Setting	Water Flow Rate per Pipe	ℓ/min	10	40	22	8.57	0.39	10	40	24	9.13	0.38	10	45	24.4	11.19	0.46
Initial Setting	Total Water Flow Rate	ℓ/min	10	40	22.7	8.25	0.36	15	80	44	18.2	0.41	20	112.5	47.9	26.7	0.56
Initial Setting	Chuck Rotational Torque	kN・m	115	265	210.5	46.5	0.22	115	265	208	46.9	0.23	140	500	248.8	102.5	0.41
Initial Setting	Chuck Rotational Velocity	mode	3.5	6	4.5	0.71	0.16	3	6	4	0.74	0.19	3.5	6	4.8	0.65	0.14
Initial Setting	Remark	–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Case2. Sand	The SPT *N*-values: 10-40		Pile Diameter φ800					Pile Diameter φ1000					Pile Diameter φ1500				
			Min.	Max.	Mean	Standard Deviation	Coefficient of Variation	Min.	Max.	Mean	Standard Deviation	Coefficient of Variation	Min.	Max.	Mean	Standard Deviation	Coefficient of Variation
			—	—	(m)	(σ)	(COV)	—	—	(m)	(σ)	(COV)	—	—	(m)	(σ)	(COV)
Machine / Material	Machine Model	–	F301/F401	F301/F401	—	—	—	F401	F401	—	—	—	SP8	SP8	—	—	—
Machine / Material	Pile Diameter	mm	800	800	—	—	—	1000	1000	—	—	—	1500	1500	—	—	—
Machine / Material	Pile Thickness	mm	9	9	—	—	—	12	12	—	—	—	16	16	—	—	—
Machine / Material	Embedded Length	m	20	20	—	—	—	20	20	—	—	—	20	20	—	—	—
Machine / Material	Lubrication System	unit	1	3	1.68	0.64	0.38	1.5	3	2.05	0.35	0.17	2	3	2.4	0.52	0.22
Machine / Material	Water Supply Pipe	–	1	3.5	2.09	0.86	0.41	2	3.5	2.36	0.55	0.23	2	3.5	2.75	0.59	0.21
Machine / Material	Pile Toe Ring Bits	–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Initial Setting	Press-in Force	×10kN	13.5	40	22	7.78	0.35	13.5	40	23	7.66	0.33	15	40	24	7	0.29
Initial Setting	Press-in Speed	mode	1	4	2.2	1.12	0.51	1	4	2.2	1.12	0.51	1	4	2.2	1.12	0.51
Initial Setting	Extraction Speed	mode	1.5	6	4.14	1.53	0.37	1.5	6	4.14	1.53	0.37	1.5	6	4.14	1.53	0.37
Initial Setting	Press-in Stroke	mm	110	1000	314	256.2	0.82	110	1000	314	256.2	0.82	110	1000	314	256.2	0.82
Initial Setting	Extraction Stroke	mm	7	100	55.8	25.8	0.46	40	105	67.8	23.3	0.34	40	125	72.5	28.6	0.39
Initial Setting	Water Flow Rate per Pipe	ℓ/min	10	50	24.5	10.65	0.43	12	50	26.3	10.28	0.39	15	50	29.2	11.86	0.41
Initial Setting	Total Water Flow Rate	ℓ/min	20	100	42	23.74	0.57	24	100	53.3	19.8	0.37	30	150	69.3	36.0	0.52
Initial Setting	Chuck Rotational Torque	kN・m	115	300	214.1	51.08	0.24	115	300	225	57.97	0.26	140	400	242.7	78.9	0.33
Initial Setting	Chuck Rotational Velocity	mode	3	5.5	4.4	0.74	0.17	3	5.5	4.4	0.74	0.17	3	6	4.5	0.88	0.2
Initial Setting	Remark	–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Case3. Gravels	The extrapolated SPT *N*-values: 50-150		Pile Diameter φ800					Pile Diameter φ1000					Pile Diameter φ1500				
			Min.	Max.	Mean	Standard Deviation	Coefficient of Variation	Min.	Max.	Mean	Standard Deviation	Coefficient of Variation	Min.	Max.	Mean	Standard Deviation	Coefficient of Variation
			—	—	(m)	(σ)	(COV)	—	—	(m)	(σ)	(COV)	—	—	(m)	(σ)	(COV)
Machine / Material	Machine Model	–	F301/F401	F301/F401	—	—	—	F401	F401	—	—	—	SP8	SP8	—	—	—
Machine / Material	Pile Diameter	mm	800	800	—	—	—	1000	1000	—	—	—	1500	1500	—	—	—
Machine / Material	Pile Thickness	mm	9	9	—	—	—	12	12	—	—	—	16	16	—	—	—
Machine / Material	Embedded Length	m	20	20	—	—	—	20	20	—	—	—	20	20	—	—	—
Machine / Material	Lubrication System	unit	1	3	2	0.65	0.33	1.5	3	2	0.45	0.23	2	4	3	0.62	0.21
Machine / Material	Water Supply Pipe	–	1	3.5	2	0.74	0.37	2	3.5	2	0.52	0.26	2	4	3	0.55	0.18
Machine / Material	Pile Toe Ring Bits	–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Initial Setting	Press-in Force	×10kN	10	35	19	6.51	0.34	10	35	20	6.38	0.32	10	35	20	6.46	0.32
Initial Setting	Press-in Speed	mode	1	4	2	1.08	0.54	1	4	2	1.08	0.54	1	4	2	0.98	0.49
Initial Setting	Extraction Speed	mode	1.5	6	4	1.53	0.38	1.5	6	4	1.58	0.40	1.5	6	4	1.53	0.38
Initial Setting	Press-in Stroke	mm	10	1000	255	253.1	0.99	105	1000	265	245.3	0.93	105	1000	265	245.3	0.93
Initial Setting	Extraction Stroke	mm	40	130	69	25.0	0.36	40	130	73	28.3	0.39	40	130	69	24.0	0.35
Initial Setting	Water Flow Rate per Pipe	ℓ/min	15	50	27	8.78	0.33	12	50	28	8.79	0.31	15	50	30	9.85	0.33
Initial Setting	Total Water Flow Rate	ℓ/min	20	80	51	18.46	0.36	35	100	58	17.3	0.3	40	150	77	29.7	0.39
Initial Setting	Chuck Rotational Torque	kN・m	115	275	210	46.62	0.22	115	300	219	53.39	0.24	140	450	231	80.7	0.35
Initial Setting	Chuck Rotational Velocity	mode	2	5	4	0.92	0.23	2	5	4	0.92	0.23	2	5	4	0.88	0.22
Initial Setting	Remark	–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Case4. Mudstone	The extrapolated SPT *N*-values: 150-200		Pile Diameter φ800					Pile Diameter φ1000					Pile Diameter φ1500				
			Min.	Max.	Mean	Standard Deviation	Coefficient of Variation	Min.	Max.	Mean	Standard Deviation	Coefficient of Variation	Min.	Max.	Mean	Standard Deviation	Coefficient of Variation
			—	—	(m)	(σ)	(COV)	—	—	(m)	(σ)	(COV)	—	—	(m)	(σ)	(COV)
Machine / Material	Machine Model	–	F301/F401	F301/F401	—	—	—	F401	F401	—	—	—	SP8	SP8	—	—	—
Machine / Material	Pile Diameter	mm	800	800	—	—	—	1000	1000	—	—	—	1500	1500	—	—	—
Machine / Material	Pile Thickness	mm	9	9	—	—	—	12	12	—	—	—	16	16	—	—	—
Machine / Material	Embedded Length	m	20	20	—	—	—	20	20	—	—	—	20	20	—	—	—
Machine / Material	Lubrication System	unit	1	4	1.82	0.96	0.53	1.5	4	2	0.75	0.38	2	4	2.77	0.82	0.3
Machine / Material	Water Supply Pipe	–	1	4	2.18	1.06	0.49	2	4	3	0.76	0.25	2	4	3.25	0.79	0.24
Machine / Material	Pile Toe Ring Bits	–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Initial Setting	Press-in Force	×10kN	11	30	20	5.46	0.27	12.5	30	20	5.33	0.27	15	30	22	4.51	0.21
Initial Setting	Press-in Speed	mode	0	4	1.7	1.15	0.68	0	4	2	1.13	0.57	0	4	1.6	1.19	0.74
Initial Setting	Extraction Speed	mode	1.5	6	3.91	1.46	0.37	1.5	6	4	1.48	0.37	1.5	6	3.91	1.46	0.37
Initial Setting	Press-in Stroke	mm	40	300	150.5	81.1	0.54	40	300	157	69.9	0.45	40	300	143.5	79.3	0.55
Initial Setting	Extraction Stroke	mm	40	100	73	19.2	0.26	40	100	79	19.8	0.25	40	100	71	17.0	0.24
Initial Setting	Water Flow Rate per Pipe	ℓ/min	15	40	25.2	7.94	0.32	12	65	32	13.23	0.41	15	50	29.3	12.25	0.42
Initial Setting	Total Water Flow Rate	ℓ/min	20	70	43.6	17.33	0.4	36	100	61	20.0	0.33	40	150	77.7	33.6	0.43
Initial Setting	Chuck Rotational Torque	kN・m	115	300	210.5	51.65	0.25	115	300	209	46.67	0.22	140	450	241.8	89.0	0.37
Initial Setting	Chuck Rotational Velocity	mode	2	5	3.8	1.06	0.28	2	5	4	1.08	0.27	2	5	4	1.16	0.29
Initial Setting	Remark	–	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

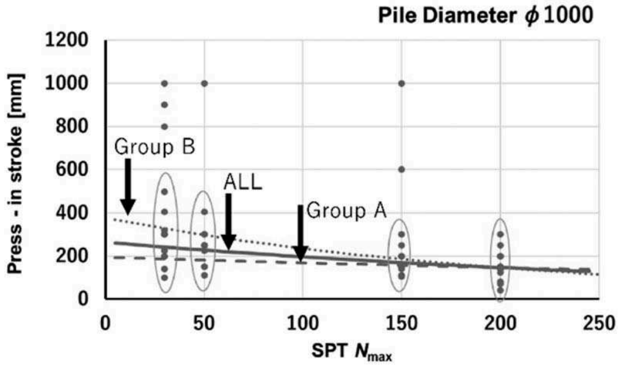

Figure 7. Relationship between press-in strokes and SPT *N*-values (1000mm diameter steel tubular piles).

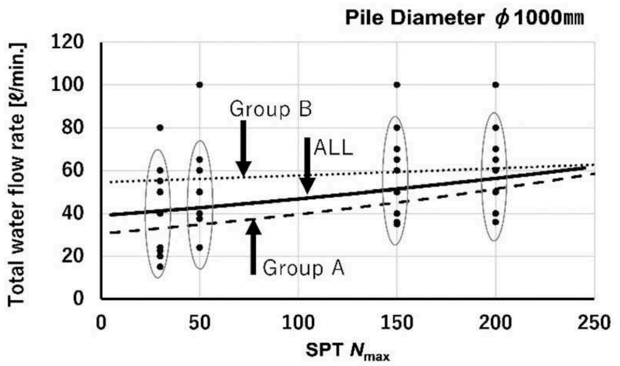

Figure 8. Relationship between total water flow rate and SPT *N*-values (1000mm diameter steel tubular piles).

– The selected number of water supply pipes is increasing as the ground stiffness increases. It is particularly so for the case of experienced operators.
– The values of COV for the press-in force are relatively small and are decreasing with the ground stiffness, while the values of COV for the press-in stroke are larger.

4.1.2 *Influence of pile diameter*

Influence of pile diameter is generally small, compared to the influence of soil profile. A general trend is that the values of COV do not vary. However, it is noticed that the values of COV of the press-in force are small, while the values of COV of press-in stroke are comparatively large. Additionally, the following points are noticed.

- For a given soil profile, the operators tend to select larger values of rotational torque and rotational velocity of chuck when the larger diameter pile is to be installed.
- For a given soil profile, the operators select a larger number of water supply pipes and a larger water flow rate when the larger diameter pile is to be installed.

4.1.3 *Influence of operator*

One of the main interests of this survey is to find out the differences of these setting values between experienced and less experienced operators. The responders were categorized into two groups: the Group A (rotary press-in piling experience equal to or more than five years) and the Group B (equal to or less than four years-experience).

It is seen that experienced operators tend to select a small number of water supply pipes, compared to those of less experienced operators for the case of clayey ground (Case 1). This tendency can be confirmed from the regression curves in Figure 8.

The vertical axis is the mean number of selected lubrication unit in Figure 9, comparing change of the number with soil profile. The figure also compares the selected numbers of lubrication unit by Group A with those by Group B.

It is clear from the figure that Group B selects the same number, regardless of soil profile. In contrast, Group A selects a smaller value for soft ground and a larger value for stiff ground, increasing as the ground stiffness increases. This suggests that the experienced operators consider the role of lubrication important and change their selection according to the stiffness of ground.

Figure 10 shows the arrangements of the water supply pipes and the direction of water flow by an arrow for the three respondents as an example. It is noticed that they arrange the pipe in such a way to discharge the water towards inside the pile for clayey ground and towards outside the pile when the ground becomes stiffer, in addition to an increase in the number of piles. This confirms the importance of a proper selection of the number of water supply pipes and a proper arrangement of the pipes for effective press-in piling.

Similar to Figure 9, the vertical axis of Figure 11 is the mean value of speed mode (The large value means that press-in speed is fast.) for four soil profiles, comparing Group A and Group B. Group

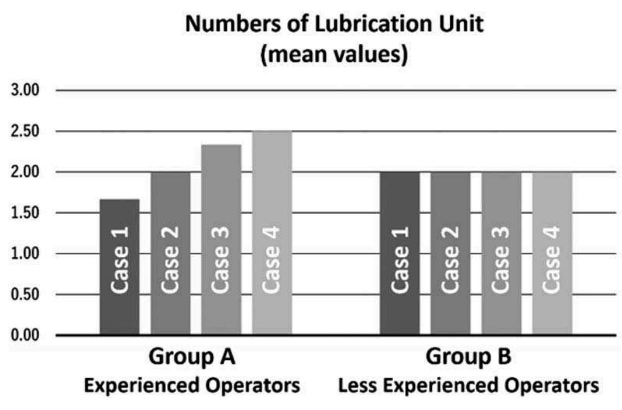

Figure 9. Comparison of experienced/less experienced operators (Unit number of water lubrication system).

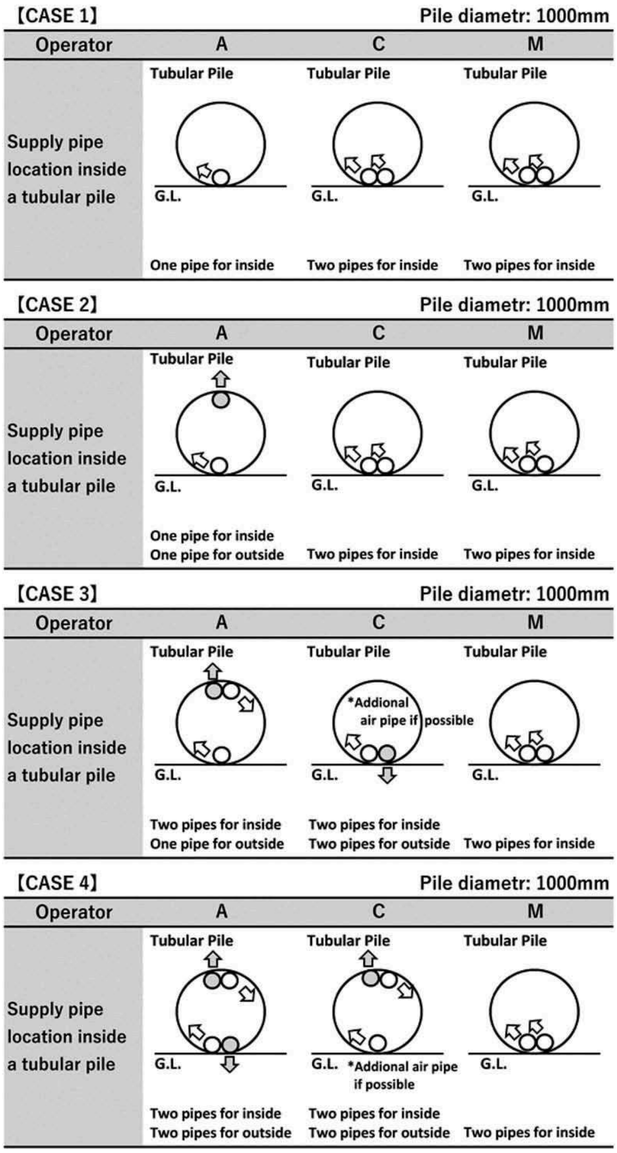

Figure 10. Examples of water supply pipe locations on each case (1000mm diameter steel tubular piles).

B operators select almost the same value regardless of the ground stiffness, while Group A operators set the press-in speed gradually lower as the ground becomes stiffer. It is also noticed that the values of Group A are generally smaller than those of Group B. A similar tendency can be seen in the chuck rotational velocity, as is shown in Figure 12. Namely, Group A operators set the slower chuck rotational velocity as the ground becomes stiffer.

Figure 13 is produced using the data from the three regression lines shown in Figure 7. The figure compares Group A and Group B, with respect to the mean value of the press-in stroke for four soil profiles. Similar to the results of Figures 9 and 11, Group A operators properly take the ground stiffness into consideration, whereas Group B operators seem less sensitive to the ground stiffness in selecting the press-in stroke.

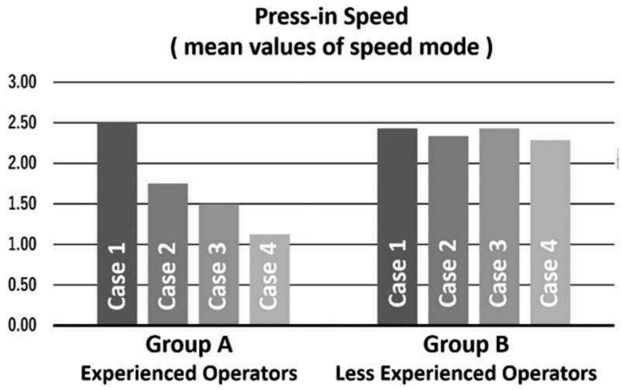

Figure 11. Comparison of experienced/less experienced operators (Press-in speed mode).

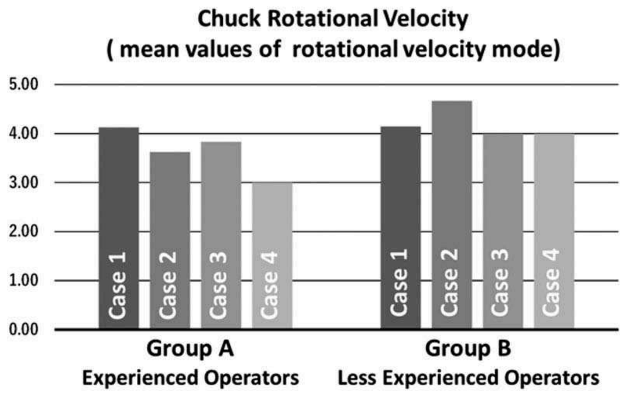

Figure 12. Comparison of experienced/less experienced operators (Chuck rotational velocity).

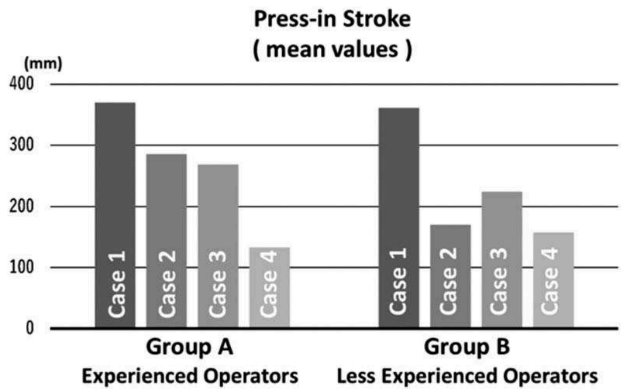

Figure 13. Comparison of experienced/less experienced operators (Press-in stroke).

This also suggests the importance of operator's skill and experience.

4.2 *Summary discussions*

The conducted questionnaire survey reveals the interesting findings related to a picture of how operators use Gyro piler on site in different soil profiles. The followings summarize the major findings.

[1] The mean value of the selected press-in force is 200kN regardless of the ground stiffness and steel tubular pile diameter, which is considerably smaller than the specification of the allowable maximum press-in force of the machine. It does not necessarily mean that the machine has unnecessary maximum capacity.
[2] More than 70% operators select the same number of water lubrication units and water supply pipes, regardless of soil profile and pile diameter. A close look at the data, there exists a difference between experienced and less experienced operators.
[3] All the operators tend to select a slower press-in speed as the ground becomes stiffer. Some operators select the same value of the press-in speed even the pile diameter becomes larger.
[4] There is a tendency that shorter strokes both in press-in and extraction are selected. This means that the number of repetitive upward and downward motion (surging) is increasing with an increasing of ground stiffness, in an attempt to avoid the formation of soil plugging at the toe of the pile and to reduce the shaft friction. For a given soil profile, the selected press-in stroke and extraction stroke are unchanged. This implies that the number of repetitive upward and downward motion (surging) is not greatly affected by the pile diameter.
[5] For a given soil profile, there is a tendency that the larger value of chuck rotational torque is selected for a larger pile diameter.
[6] Due to the prevention not to wear out cutting bits at the pile toe, experienced operators select a slower chuck rotational velocity for stiffer ground. As a result of it, machine damages might be reduced. In contrast, less experience operators select the same value of the speed. This finding implies that some causes of machine damages may stem from operator's skill and experience.
[7] The value of COV of the operator's responses becomes larger as the ground becomes stiffer.

5 CONCLUDING REMARKS

With the view that performance of the final product of piles installed largely depends on the operator's skill with a proper handling of the machine, this study began. This paper firstly pointed out that effective piling operation can only be achieved by a good combination of a well-maintained machine and a skillful operator.

The questionnaire survey thus conducted revealed the interesting findings related to a picture of how operators use Gyro Piler on site in different soil profiles. From the above, it is clear that there is a tendency that the experienced and skillful operators carefully chose the values of initial setting of the machine operation and the number and arrangement of water lubrication system in order for smooth piling operation and for avoiding a possible risk of damaging the machine, taking into account the soil profile and the pile diameter. It is also noticed that the less experienced operators tend to select the similar initial setting values regardless of soil profiles.

The survey confirms that the operator's experience and skill play an important role for effective press-in piling with a minimum risk for damaging the machine. The information summarized in this paper may be regarded as valuable rules of thumb from know-how that experienced operators gain on site.

This survey was limited to cases of Gyro Piler. Further survey is planned to carry out for cases of other press-in machines with another group of operators. Further study will be of use for the future development of piling machine for machine designers. The accumulated know-how will become an essential database for developing an automatically operating system as a deep learning database based on AI technology.

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