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Summary of case histories of retaining wall installed by rotary cutting press-in method

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ABSTRACT: This paper summaries Japanese case histories of retaining walls of the rotary cutting press-in piles in terms of the application, pile materials, project scale, spatial restrictions for working, and ground conditions. The purpose is to grasp the characteristic of the rotary press-in method, and grasp the requirement for the renewal of civil infrastructures under working restrictions. The rotary press-in piles were often used when the pile diameter was 1000 mm, the pile length was 18–20 m, and the total length per project was 20–40 m. About 70% of the projects for reconstruction/rehabilitation of the retaining structures had spatial restrictions, such as insufficient headroom, side space and working space, and unstable work at high places. And over 60% of the projects had problems of hard grounds (SPT N>75) or any underground obstacles.

1 INTRODUCTION

Cantilever steel pile retaining walls are increasing under restrictions of working sites (Miyanohara et al. 2018). Although they have been mainly used as temporary earth retaining walls in the past, they also have recently been used as permanent structures in Japan. IPA-TC1 has been investigating their rational design methods in relatively hard ground and discussing the safety of the walls in short embedded depth (e.g. Kunasegaram et al. 2018).

Types of the earth retaining walls are determined based on many criteria, such as cost, ground conditions, water cut-off, speed of construction, the presence of obstructions, environmental issues, and others (Gaba et al. 2017). Types of wall construction methods include king post walls (as known as soldier piles), sheet pile walls, steel pipe pile walls, cast in-situ piles (contiguous/secant), and diaphragm walls (D-wall) (e.g. Long 2001, JRA 1999). Generally, sheet piles are used for temporary or small-scale excavation, and D-walls are used for large-scale excavation. The steel pipe pile walls are used for the in-between scale, and one of its advantages are it has little danger of soil contamination and it does not require large working area for cage, pumping equipment and concrete plant.

The rotary press-in piling method, which we introduce in this paper, is one of the representative installation methods of steel pipe pile retaining walls (Figure 1). The rotary press-in enables pile rotation by omitting joints (i.e. it use steel pipe piles instead of steel pipe sheet piles). It greatly expands the application range of hard ground, which is generally a problem in steel pipe pile installation methods. And environmental issues such as noise and vibration are less than those of driven pile or other piling methods.

This paper will summarize Japanese case histories of the rotary press-in piling method. The original purpose is to grasp the characteristics of the rotary press-in method. A secondary aim is to grasp the requirements for the retrofits of civil infrastructures under working restrictions.

2 JAPANESE CASE HISTORIES OF ROTARY CUTTING PRESS-IN METHOD

The rotary cutting press-in method was developed by Nippon Steel and GIKEN LTD. It presses and rotates a pile by grasping the previously pressed steel pipe piles for the reaction force. The machine moves over the steel pipe pile heads and constructs the wall in a row (Figure 1). It was first applied to the construction project in 2004, Japan, and now the accumulated number of the projects becomes 442 (Figure 2). Of these, 25 used Clamping Crane, which load piles with self-walking system, and 24 used Clear Piler, which is one of the pilers for operations under low headroom.

Compared with other installation methods of steel pipe piles, the rotary press-in method has following advantages and disadvantages (e.g. Hirata and Matsui 2016);

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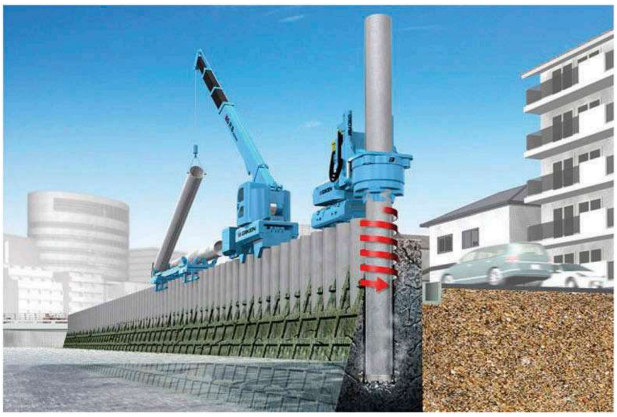

Figure 1. Rotary cutting press-in method (IPA 2016).

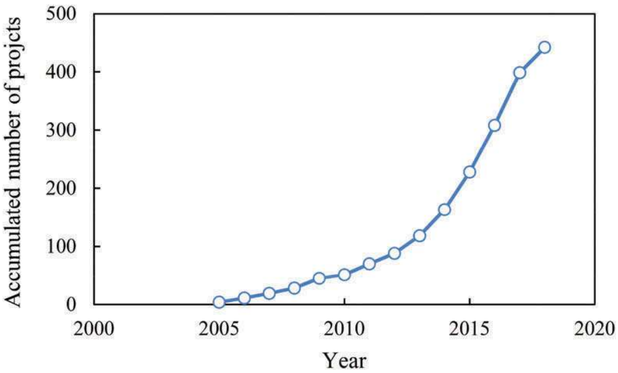

Figure 2. Accumulated number of the application of the rotary press-in method.

Advantages:

- Low noise, low vibration and a small amount of water discharges.
- Short construction period with no temporary structures and little disposal of soil
- Used in a wide variety of soils including underground obstacles such as concrete structures.
- Construction under the girder of the existing bridge or close to a road or railway, is also applicable.

Disadvantages:

- High cost.
- Issues to cut off water.
- Long embedment depth is needed for reaction force if the ground is very soft

2.1 *Application of rotary press-in method*

A total of 442 projects of the rotary press-in piles have been completed as of the end of September 2019, which GIKEN identified. About 40% of the rotary press-in piles has been applied for river structures (Figure 3).

The distribution of the structure types of the rotary press-in piles is shown in Figure 4. The classification of the structure is based on IPA (2016). The rotary

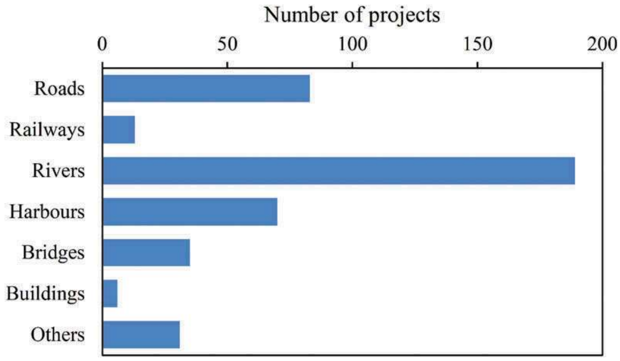

Figure 3. Application of the rotary press-in method.

press-in method was applied to various types of constructions. In road construction, it was mainly used for widening roads and for reinforcing slopes against disasters (a and b). Although fill slopes with retaining walls (a-1) of rotary press-in were less common than cut slopes (a-2), they may be used due to restrictions in the delivery route to the construction site. Constructions close to existing buildings behind the retaining walls made it difficult to use cranes and vibratory equipment (a-2 and a-3). More than half of the projects have been adopted in rivers and harbours (c-e). Since river/sea walls require to be reconstructed or rehabilitated while leaving their functions, discarded rubbles can make it difficult without the piling method. When an urban highway passes over a river revetment, equipment for low headroom would be required (c-2). Constructions under existing piers and abutments in service demand little noise and vibration in order not to interfere with railroad operations (f-1). It was also used for the foundations of seawalls because press-in method has advantage to install in a row (f-2). A few of temporary constructions adopted it especially in hard ground and under narrow working spaces, although steel pipe piles are relatively expensive and difficult to be extracted (g).

To focus on retaining structures, the following will consider 345 cases except for bridge foundations (f), temporary works (g), and others/unknown (h).

2.2 *Pipe pile material*

The most common pile diameter, D, was 1000 mm, which accounted for 40% of the totals (Figure 5). The number of projects whose pile diameters were larger than 1000 mm was been increasing and accounted for about 30% of the totals because of the development of new equipment for large diameter piles.

Figure 6 shows ratio of the pile thickness. The ratio was the number of projects divided by the sum of those with the same pile diameter. The lower/upper pile thickness were also drawn. The lower pile thickness is generally 1% D (limited to a minimum of 9 mm) in Japan for workability (e.g. JRA 2017). The minimum thickness was the most commonly used for almost all pile diameters.

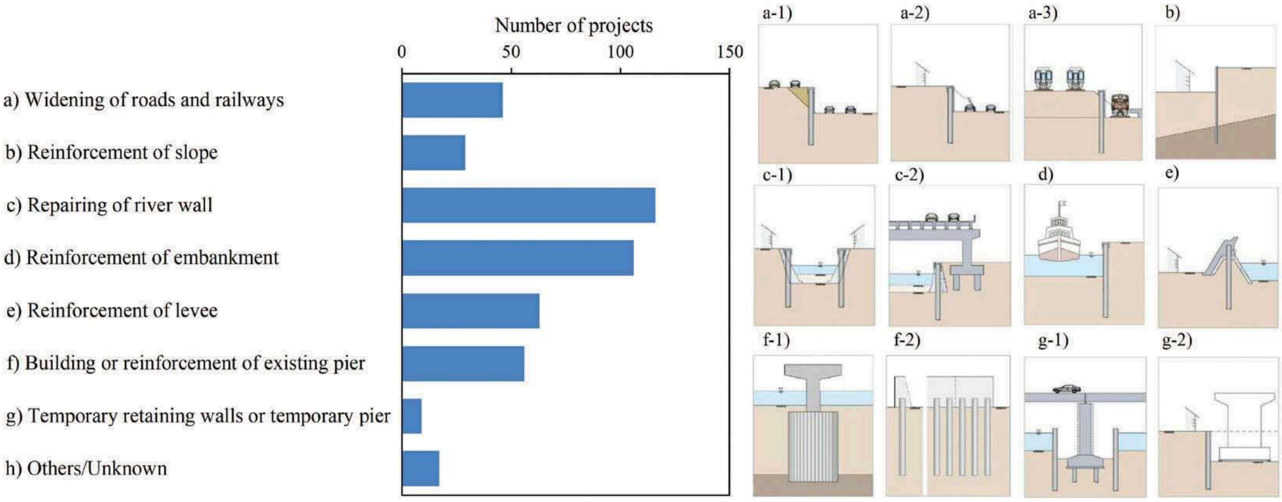

Figure 4. Types of constructions with rotary press-in piles (after IPA 2016).

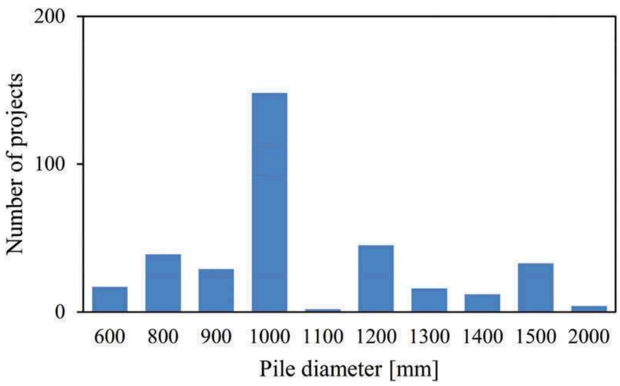

Figure 5. Distribution of pile diameters. Inch size pile diameter was truncated by 100mm. With using multiple piles in the same project, the maximum pile diameter and the maximum pile length were shown.

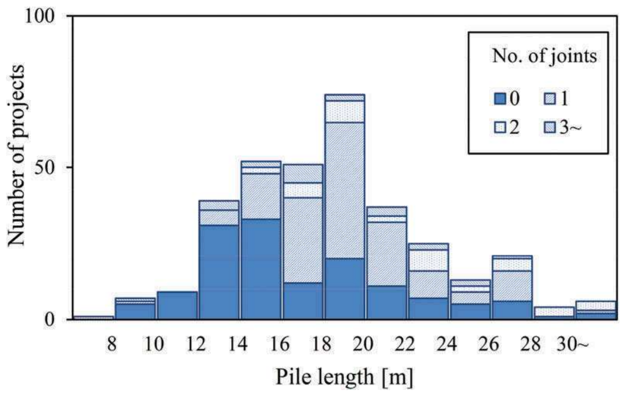

Figure 7. Distribution of pile length and the number of joints.

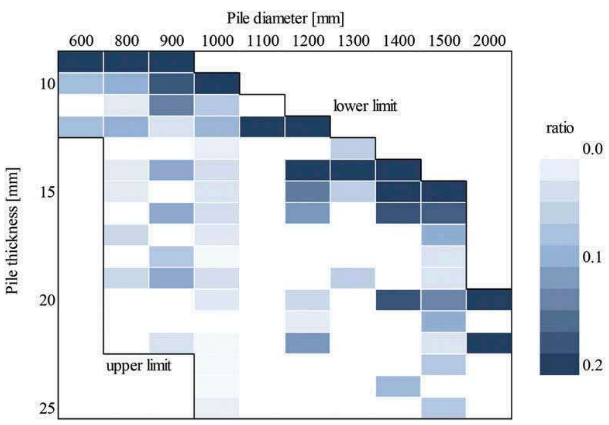

Figure 6. Heatmap of the project ratio of pile thickness.

Figure 7 shows the distribution of the pile length and the number of joints. The most common pile length was 18–20 m, and there were some examples of piles with a length of over 30 m (constructed maximum length is 53.0 m). In Japan, the length of piles is restricted for the safety of road transportation, and piles exceeding some length are required to have a permit for transportation on the road. Thus, construction work with a pile length of over 12 m was likely to have joints.

One or more vertical joints are required for about half of the total projects. Some restrictions such as low headroom increase joints, which take time to join and inspect the joints.

Though we haven't grasped the height of structures or excavation depth of all cases, 13 m (*D*: 2000 mm) and 10.5 m (*D*: 1500 mm) of wall heights are one of the highest cantilever walls observed (Miyanohara et al. 2018).

2.3 *Construction scale*

The scale of construction per project was mostly 20-40 piles (Figure 8) and 20–40 m in total length (Figure 9), and projects over 40 piles and 40 m length accounted for more than half. Large scale construction can spend more time and cost on geotechnical investigation and design for rationalization.

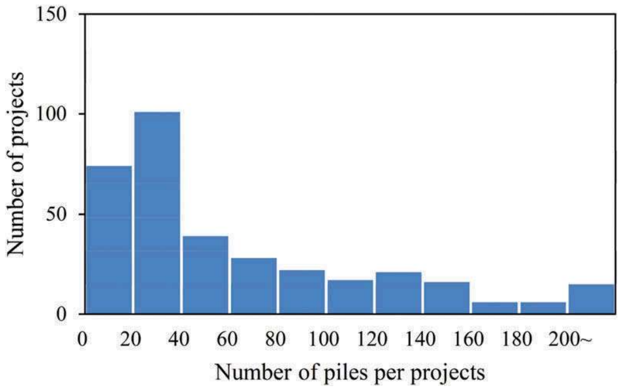

Figure 8. Distribution of the number of piles per site.

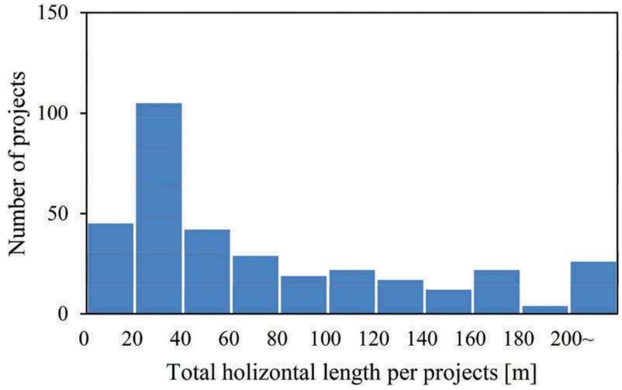

Figure 9. Distribution of total length per project.

2.4 *Spatial restrictions for construction operation*

The rotary press-in method can be subject to the following spatial restrictions depending on the site conditions: narrow space for installation disturbs the construction, high-level work makes the machine unstable, and insufficient space for machine movement, temporary storage, and crane installation reduces efficiency.

Figure 10 shows the restrictions during construction and their distribution. Since these results are based on the work for a cost estimate, they may differ from the actual. In case the data are not available, the adjacent field conditions are alternatively used. The strictest conditions are applied where the projects have more than one standard cross-sections. We exclude anything unknown as "unknown".

About 40% projects except for the unknown has severe restrictions for side space, with less than 5 m (Figure 10b). In contrast, the restrictions for the working yard width are less severe (Figure 10d). The standard working yard width of the rotary press-in method is about 12 m which is almost the same as other earth retaining methods (JSCE online). Though the ratio of cases with the high-level installation is also not so large (Figure 10c), other common earth retaining methods require the construction on a leveled condition (e.g. all-round rotating machine and machinery for diaphragm wall), which can be a determining factor. Finally, though the ratio of cases with headroom restrictions is less than other restrictions (Figure 10a), it also can be a determining factor, because other methods find it difficult to install piles over water and under head-restrictions of 5 m.

As for the relationship between spatial restrictions and the applications, constructions for slope reinforcement (Figure 4a-2) tend to require severe lateral restrictions, and those for river wall (Figure 4c) tend to require severe restrictions of upper and side space. Also, about 70% of the projects except for "unknown" have one of the spatial restrictions.

2.5 *Geotechnical restrictions*

A total of 128 projects are used from the projects that introduce the pile layout and ground conditions on the Japan Press-in Association website. Since the

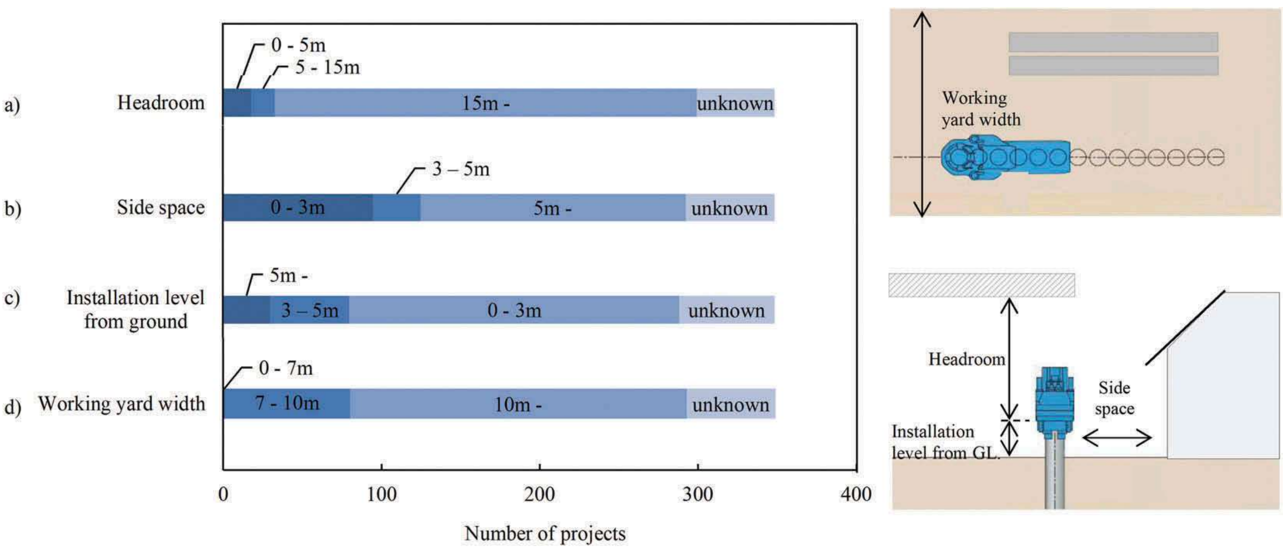

Figure 10. Spatial restrictions for working (based on works shown in Appendix).

information is not exhaustive and is collected from constructors intending to advertise the rotary press-in method unlike the previous, it should be used with caution. However, we believe it contains enough examples to grasp the characteristics of the rotary press-in method.

Figure 11 shows the relationship between the maximum converted SPT-N value and the ground type. Impenetrable layer was represented by N value of 300 or more. If fields had existing structures, obstacles and rubbles which piles had to be penetrated, they set the N value to the maximum N value of the ground other than those and sets the ground type to "other". Otherwise, the ground type represents the one with the maximum N-value. Rock includes consolidated silt. The maximum constructed unconfined compressive strength (UCS) of rocks was 98 MPa (IPA 2016). The "other" (existing structures, obstacles and rubbles) applies for about 20%, and gravels and rock with an N-value of 300 or higher account for another 20%.

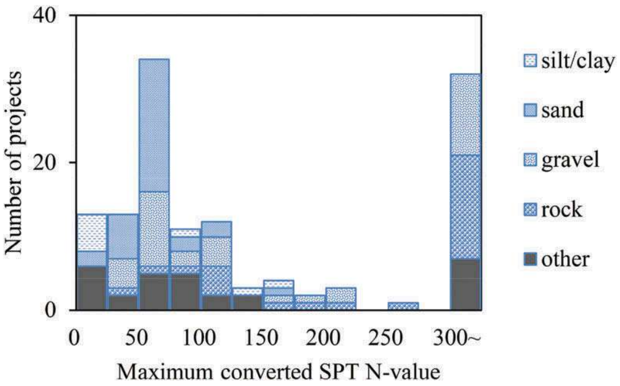

Figure 11. Maximum converted SPT N-value and ground type in the rotary press-in method.

About 40% of the ground had an N-value of 75 or lower and no existing structures, where press-in method associated with water jetting can also install piles (IPA 2016). Also, most of the remaining cases which had no problems of hard ground and obstacles, had the spatial restrictions.

2.6 *Environmental restrictions*

Low noise and low vibration were also required in most cases, though the qualitative number was not grasped. The power-unit used in the rotary press-in method has been specified as low-noise and low-vibration construction equipment by MLIT (2020).

The environmental restrictions also include the requirement of short construction period. For example, where the construction work must be carried out during the drought season and there is little time to build temporary stages, the press-in method has advantages.

3 SUMMARY

This paper over-viewed Japanese case histories of the rotary press-in piles in terms of the application, pile materials, spatial restrictions, and ground conditions. The case histories supported the characteristics of the rotary press-in method which Hirata and Matsui (2016) mentioned. About 70% of the projects for retaining structures with the rotary press-in method had one of the spatial restrictions; a: headroom restrictions, b: side-space restrictions, c: high-level working, and d: insufficient working space. Besides, over 60% of the projects have problems of hard ground (N>75) and obstacles. Figure 12, an illustrative diagram, summarizes the restrictions of the projects which adopted the rotary press-in method for retaining structures.

Besides, Jitsuhiro (2004) investigated case studies on road business risks in Japan and reported which accidents increased construction costs. The report has listed the following accidents with high costs and a high probability of occurrence: i) difficult land negotiations, discussions on environmental measures, and discussions on routes and structures (at design and planning), and ii) coping with unexpected geological conditions and with underground buried objects (during construction). Since these unfavorable accidents will increase in the future and the rotary press-in method has the potential to avoid them as shown in this paper, we expect more adoptions to occur.

This paper did not intend to introduce the rotary press-in method completely, since the reason for the adoption differed from site to site. A combination of this paper and other case histories (e.g. IPA 2019) will be helpful to grasp the features of the rotary press-in method.

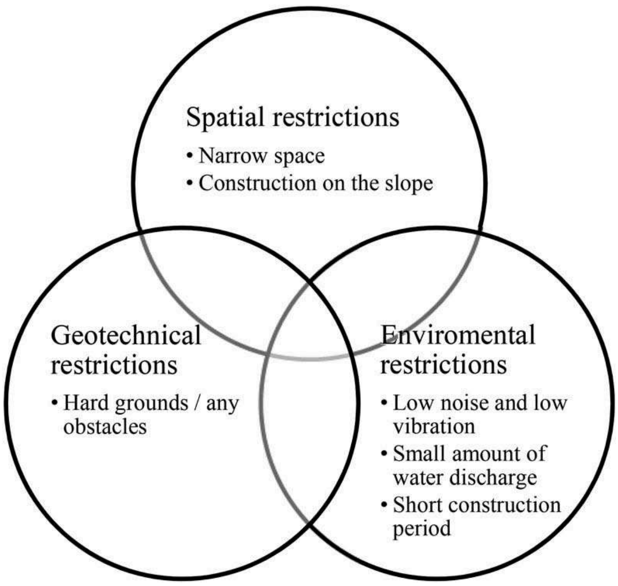

Figure 12. Illustrative diagram of restrictions of construction which adopted the rotary press-in method for building retaining structures.

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APPENDIX

An outline of the cost estimation of the rotary press-in method in Japan is described (JPA 2019). It is usually used by clients for assuming the reasonable construction method and estimating the appropriate cost, before placing an order for Japanese public construction.

a) Construction time

The construction time, T, is the sum of the installation time of the pile itself and the joint member therebetween, T_c and T_h. T_c is calculated as;

$$T_c = (T_S + T_B)/F + T_w \tag{A1}$$

where T_S: preparation time, T_B: press-in piling time, T_w: welding time, F: work factor.

T_S includes setting piles, centering adjustment, installation/removal of driving attachment and swivel for water lubricating systems, self-walking, preparation for welding, welding of steel sheets on pile heads, and others.

$$T_S = 1.15L + 23.8 + 20n \text{ min} \tag{A2}$$

where L: pile length [m] and n: number of joints.

Press-in piling time, T_b, is calculated as;

$$T_B = \sum \gamma_i l_i \tag{A3}$$

where γ_i: unit press-in time per meter for each soil layer, l_i: press-in length for each layer.

γ_i is calculated by the average SPT-N value for each soil layer, N_{avg}.

$$\gamma_i = 0.054N_{avg} + 1.32 \text{ min/m} \tag{A4}$$

T_w depends on the pile diameter, thickness and the number of joints.

b) Operation cost

The pile installation costs consist of the operation of the press-in machine, rent of the water lubricating

Table A1. Correction factor for work coefficient.

Correction factor		unit	–0.10	–0.05	0.00	+0.05
f_1	Headroom	m	Under 10	10–15	15 or more	—
f_2	Side space	m	Under 3.0	3.0–5. 0	5.0 or more	—
f_3	Installation level from ground	m	5.0	3.0–5. 0	Under 3.0	—
f_4	Working yard width	m	-	7.0–10.0	10.0 or more	—
f_5	The number of piles per block	-	30–50	50–100	100–200	200 or more

Note: If there are special working conditions/restrictions, an estimation has to be carried out at each site.

system, labour charge, sundry expenses, and others. Each unit price depends on the country or region.

c) Work factor

Work factor, *F*, is based on site conditions; headroom, side space, installation level from the ground, working yard width, and the number of piles at the project (Table A1). These conditions effect the efficient work.

$$F = F_0 + \sum f_i \quad \text{(A5)}$$

where F_0: base factor (=1.0), f_i: correction factor with each condition.