Reuse of removed electric PC pole to ground reinforcing member

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ABSTRACT

Tokyo Electric Power Company Holdings, Inc., the Japanese largest electric power supplier, has about six million of electric and telecommunication pre-stressed concrete (PC) poles over its service area. Standard electric PC pole has a length of about 14m with high flexural rigidity. Several ten-thousands of these poles are annually removed for various reasons such as underground installation of power cable and widening the road width. Up to the present time, these removed poles have been crashed into scrap-iron and crashed stone for recycling use. The recycle option, however, requires considerable energy and produces CO_2 emissions. To aim for reduction of CO_2 emissions, a study is underway to examine the feasibility to reuse the removed poles as a foundation pile, by cutting the pole length into half and/or vertically splitting the pole into two or four. Three types of pile are considered: short hollow pole and semi-circular or quarter circular shape plate by splitting. The short hollow pole may be installed into ground as a foundation pile, whereas the semi or quarter shape plate may be used as a ground reinforcing member. Possible methods of installation of these foundation pile/reinforcing plates include press-in, press-in with pre-boring, rotary press-in with surging, depending on the soil condition. Two series of field test revealed that the proposed concept of reusing the removed PC pole, previously crashed, is feasible and a promising option for contributing to reduction of CO_2 emissions in piling industry.

Key words: *Reuse, PC pole, Reinforcing member, Press-in, Rotary Press-in*

1. Introduction

The Paris Agreement was adopted in December 2015. Nationally determined contribution of Japan states 26% reduction of global warming gas emissions by 2030 compared to those in 2013 (Global warming prevention headquarters, Japan, 2015). The Japanese data of 2021 reveals that the industrial sector is responsible for about 30% of the total CO_2 emissions (Japan Center for Climate Actions, 2021) and various efforts are intensively underway to reduce CO_2 emissions in the industrial sector.

This paper introduces a recent attempt by an electric power company to reduce CO_2 emissions by shifting a re-cycle option to a re-use option in dealing with removed electric PC poles. Several ten-thousands electric PC poles are removed every year, mainly due to underground installations of power transmission cables, and widening road widths.

The paper describes firstly the role and structural features of the electric PC pole, and then considers the feasibility of utilizing the removed PC pole as a ground reinforcing member or a foundation pile. The paper subsequently reports the results of preliminary loading tests at two different sites to confirm the high potential of re-use option of the removed PC pole for reducing CO_2 emissions in piling practice.

2. Electric pole

2.1 Role and structural features of electric pole

Electric pole is a pre-stressed concrete structure which supports electric cables and telecommunication lines in the networks of electric power and telecommunication owned by electric and/or telecommunication companies, as is shown in **Photo1**. Structural specifications of the electric PC pole are given by Japanese Industrial Standards (JISA5373).

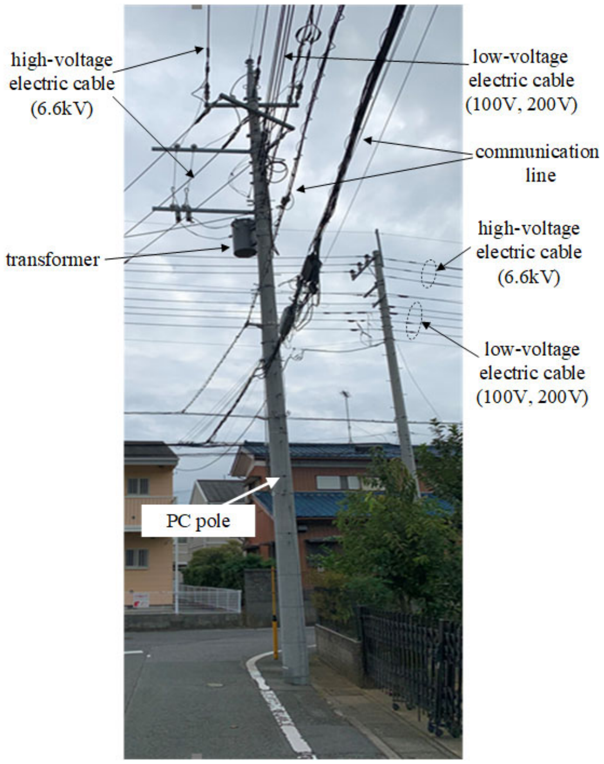


Photo 1 A view of electric PC pole

For cases of most frequently used 14 m long electric PC pole, the electric pole is structurally designed as a cantilever beam with an embedment of 2.5m, subject to tensile forces of the electric cables located at the upper part of the pole. Thus, the electric poles must sustain large bending moments. The pole diameter is also required to be as small as possible, to minimize the disturbance to road traffic and other environmental requirements.

Together with the above requirements such as smaller dimensions and higher bending stiffnesses, the pole needs to be designed not to generate wider cracks in the pole to ensure higher durability. Pre-stress is thus introduced to prevent the propagation of cracks, together with the use of high strength concrete and the larger amount of reinforcing steel bar. Typical design specifications for the electric PC poles are given in **Table 1**.

Table 1 Design specifications

Item		Value	Unit
Length of pole		14,000	mm
At the tip of pole	Outer diameter	190	mm
	Inner diameter	106	mm
At the base of pole	Outer diameter	377	mm
	Inner diameter	293	mm
Thickness		42	mm
Taper		1/75	
Embedded depth		2,500	mm
Designed compressive strength of concrete		63.7	N/mm^2
Steel ratio	At the tip	2.06	%
	At the base	1.69	%

2.2 Manufacturing process of electric PC pole

The electric PC pole is generally manufactured following a series of processes presented in **Fig. 1**.

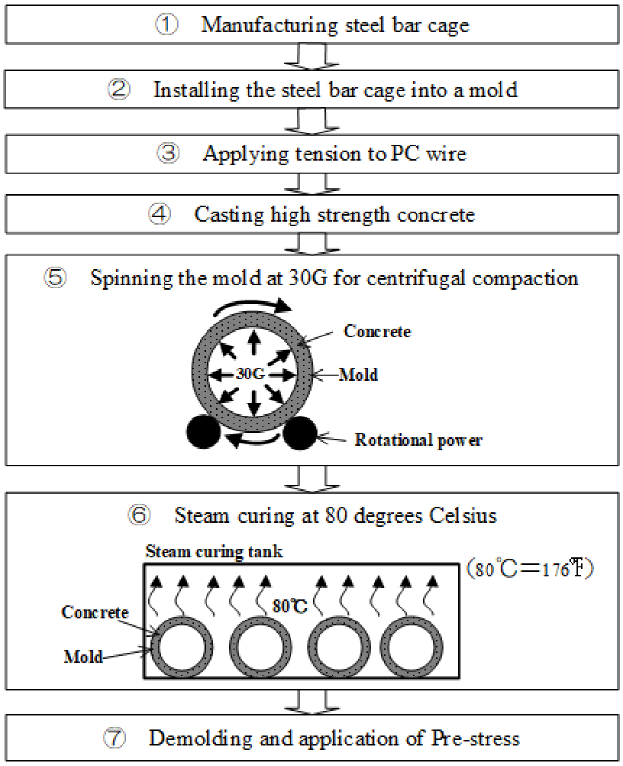


Fig. 1 Processes of manufacturing PC pole

There are two important processes. which are firstly, the centrifugal compaction process under 30 G for achieving strength uniformity in the circumferential direction as well as thick high strength concrete, and secondly, the steam curing process under 80 degrees Celsius for allowing uniform strength development. The reinforcement drawing of the PC pole is given in Fig. 5.

3. Removal process on site and mechanical properties of removed PC pole

When removing 14m long PC poles, the poles are cut into two in length on site. The reason for this practice is that the maximum length of 12m is conveniently transported by a vehicle as well as for the ease of removal work on site. Up to the present time, the removed poles undergo re-cycle processes, utilizing them as two re-cycle materials: scrap-iron and crashed stone. **Figure 2** illustrates the re-cycle processes.

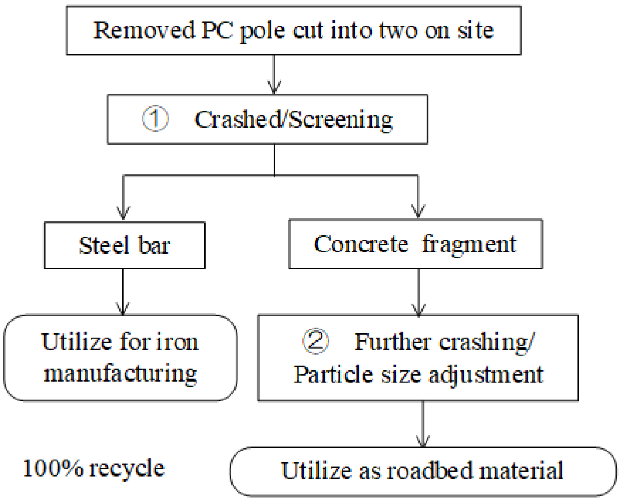


Fig. 2 Material re-cycle of removed PC pole

Removed poles stand on site in service for a relatively long period of time. Thus, there is a concern about their durability for re-use purposes. To examine the durability of concrete poles due to age degradation, an intensive study was conducted for railway PC poles (Ueda et al. (2004)). The writers examined as many as 475 PC poles which were in service ranging from for 1 year to for 56 years.

The study concluded the following aspects.

(1) Marginally carbonation progresses.

(2) It has a certain resistance against the penetration of Chloride ions.

(3) An alkaline-silica reaction hardly occurs.

(4) Degradation may progress at the joints of the mold if watertightness is not adequate during the centrifugal compaction, causing the mortar squeezing out.

As for the carbonation, Masuda and Abe (2009) gathered a number of the data of carbonation rate for various 28day compressive strengths. They plotted the data of the coefficient of carbonation rate (the neutralizing speed coefficient) against the 28day compressive strength as is presented in Fig.3. From the figure, they obtained a regression curve between the coefficient of carbonation rate and the 28day strength. By extrapolating the regression curve, the coefficient of carbonation rate becomes zero at the compressive strength of around 60.0 kN/m^2. As was given in Table 1, the design compressive strength of the removed PC pole is 63.7kN/m^2, suggesting that the carbonation rate may well be negligible for the PC pole.

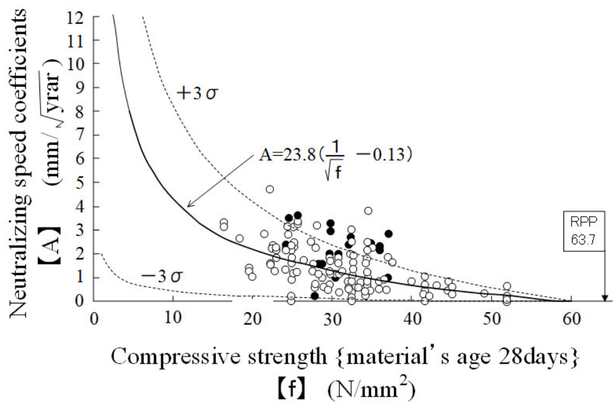


Fig.3 Neutralizing speed coefficient against compressive strength (Reproduced from Masuda and Abe, 2009)

Based on the previous studies mentioned above, it is considered that the durability of the electric PC pole is satisfactorily high enough to reuse, provided that detailed quality inspections are carried out at the joint part, together with proper visual inspections on cracks and defects. Detailed methods of the quality inspections are described later.

Furthermore, it is expected that the removed PC poles could be effectively used for a ground reinforcing member or a foundation pile, since mechanical environments in the ground may be less sever, compared to the environments in the normal use condition of PC poles on site, which are subjected to large bending moment and are exposed to the air.

4. Reuse of removed PC pole

4.1 Ground reinforcing members made from the removed PC pole

The removed poles to be reused are selected, prior to the crashing process, after confirming that the quality and visual inspections are satisfactory as a ground reinforcing member. The selected poles are then modified into reinforcing members, compatible to other ground reinforcing members currently adopted, with respect to geometrical dimensions, weight, required transport vehicles and availability of installation machines.

Three types of modification are considered feasible, as is illustrated in **Fig. 4**. The upper half of the removed PC pole is used as a tapered hollow member (called short hollow pole, hereafter), and the bottom half is cut by a cutting machine (MIKASA Engine semi-automatic cutter MCD-315HS) into either two or four parts in the vertical direction, forming semi-circular or quarter-circular reinforcing member (called semi-circular plate, quarter-circular plate respectively, hereafter). Cutting process does not take long time, about 5min. in the horizontal cutting and about 15 min. in the vertical cutting for 6m long pole.

It should be remembered that the short hollow pole and the semi-circular short pole are produced from the upper half of the removed PC pole, whereas the quarter-circular plate is created from the bottom half of the removed PC pole, resulting in different CO_2 emissions during the re-cycle processes, as will be given in Table 2.

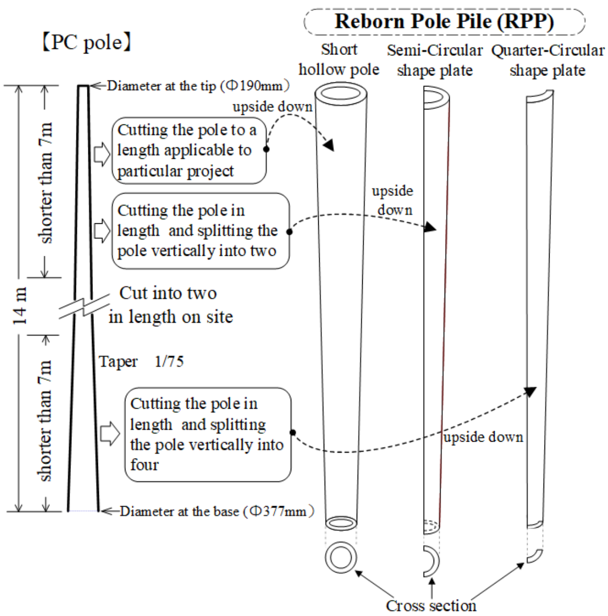


Fig. 4 Illustrations for how to modify removed PC pole into reinforcing members

Photo 2 shows the three types of reinforcing members produced from the removed PC poles. Commercial name of these reinforcing members is Reborn Pole Pile (abbreviated as RPP hereafter).

Photo 2 Views of three types of RPPs

4.2 Quality inspections

RPP must be satisfactory passed through the following three stages of the quality inspections as an accepted product.

(1) Visual inspection

Prior to modify the removed electric PC pole, visual inspections are carried out as to whether there is no large crack, no defect, no rust fluid, and no deflection. After the modification, similar visual inspections are repeated again.

(2) Degradation diagnosis

To ensure that there is no sign of carbonation around steel bar, the cut section is examined by the carbonation test of spraying phenolphthalein liquid (**Photo 3**).

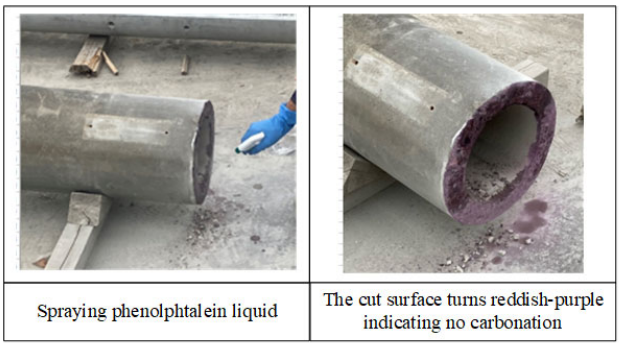


Photo 3 Carbonation test of spraying phenolphthalein liquid

(3) Compressive strength diagnosis

Schmidt hammer tests are performed on the cut section to confirm the adequate compressive strength (**Photo 4**).

Short hollow pole	Quarter-Circular shape plate
	

Photo 4 Schmidt hammer test

5. Evaluation of reduction of CO_2 emissions

It is expected that the re-use option contributes to reduce CO_2 emissions. Quantitative and rigorous evaluation is rather difficult, and it will form a future research subject. However, simplified estimations were attempted in two aspects described below for examining the possible merits of the re-use option.

5.1 Reduction of CO_2 emissions

In the re-cycle option, the removed PC poles are crashed into steel bar and concrete fragment (① in Fig.2). Concrete fragments are further crashed to crashed stone (② in Fig.2), of which the maximum diameter is typically 40mm.

In order to compare the amount of CO_2 emissions during the re-cycle option, hearing from recycle companies were conducted and the data of the annual production volume of recycled crashed stone in 2021 was gathered by the first author (Yamazaki, 2023). From the gathered information, the amounts of CO_2 emissions were calculated both due to the fuel consumption of crashing machine for the removed PC pole, and due to the power consumption of screening machine for crashed stone. Subsequently the total amount of CO_2 emissions per unit weight during the re-cycle processes was estimated. On the other hand, during the re-use option, the amount of CO_2 emissions due to the fuel consumption of cutter machine during RPP modifications was calculated. By which, the total amount of CO_2 emissions per unit weight during the re-use option was evaluated.

Table 2 is the comparisons of CO_2 emissions for the three types of modifications and the corresponding CO_2 emissions in the re-cycle option. The table indicates that a substantial reduction for CO_2 emissions is obtained by shifting the re-cycle option to the re-use option. Namely, the CO_2 emissions of the short hollow pole is 3% of those of the corresponding re-cycle option, the semi-circular shape plate 16%, the quarter-circular shape plate 19%, respectively.

Table 2 Comparison of CO_2 emissions

	CO_2 emissions (kg-CO_2)	
	Re-cycle process	RPP manufacturing
Short hollow pole	3.69	0.105 (3%)
Semi-Circuar shape plate		0.609 (16%)
Quarter-Circuar shape plate	6.30	1.218 (19%)
The number in the brackets is a ratio relative to re-cycle process		

It should be noted here that the data of the fuel consumption of the cutter machine used in the above calculation is not those used in the actual RPP modification, but those in the cutter machine for pavement. Further data collection is needed in this respect.

5.2 CO_2 emissions during manufacturing ground reinforcing members

The data of CO_2 emissions during manufacturing are available for three different reinforcing members currently used. These are H type Pre-stressed High-strength Concrete pile, steel pipe pile and cement-treated improvement of pillar type. As a working example, the following conditions were considered for comparison purposes, considering a typical detached housing development in Japan as Building area of 75 m^2, Number of ground reinforcing members of 37, and Length of ground reinforcing member of 6 m.

The amount of CO_2 emissions during manufacturing can be evaluated by a unit weight of CO_2 emissions multiplied by the volume of the reinforcing members. The CO_2 emissions for H type Pre-stressed High-strength Concrete pile were the sum of the CO_2 emissions during the production of cement and steel bar. The CO_2 emissions for steel pipe pile were the CO_2 emissions of steel production, and the CO_2 emissions for cement-treated improvement of pillar type were that of the cement production.

The results of the CO_2 emissions per reinforcing member of 6m long are tabulated in **Table 3**. Based on the values in the table, the total amount of CO_2 emissions per house can be calculated by multiplying the CO_2 emissions per reinforcing member of 6m long by the number of ground reinforcing member of 37. Thus, the re-use option reduces about 2,000 to 11,000 kg-CO_2/house, because the re-use option generates no CO_2 emissions for the manufacturing process.

Table 3 Comparison with existing methods

Method	unit CO_2 emissions	CO_2 emissions for 6m long reinforcement	CO_2 emissions in manufacturing cement + steel (kg-CO_2)
① PHC pile (H type)	0.8 kg-CO_2 / cement kg	65×0.8＝52 (kg-CO_2)	60.2
	2.2 kg-CO_2 / steel kg	3.744×2.2＝8.2 (kg-CO_2)	
② Steel pipe pile	2.2 kg-CO_2 / steel kg	44.34×2.2＝97.5 (kg-CO_2)	119.5
		10×2.2＝22 (kg-CO_2)	
③ Cement -treated improvement (pillar type)	0.8 kg-CO_2 / cement kg	353×0.8＝282 (kg-CO_2)	282
RPP			0

6. Suitable soil type of installing RPP

Solid inclusion into the ground leads to (1) densification of surrounding cohesionless soils and (2) for saturated cohesive soils, generation of excess pore water pressure, and subsequently dissipation of excess pore water pressure, resulting in the increase in shear strength with time. Ground response to solid inclusion into clay has been numerically examined (Randolph, Carter and Wroth, 1979). Detailed observations of soil movement around the tip of penetrating pile were previously made for two-dimensional plate (White, 2002) and for open-ended pipe pile (Kikuchi et al. 2008).

The rate of increasing shear strength with time is accelerated when the reinforming members are permeable. There is a series of 14mm diameter scaffold along the electric PC pole with about 450mm interval mainly for maintenance purposes, as is shown in **Fig.5** For the case of a 6m long pole, a total of 25 scaffold are installed. At these concaved parts of the scaffold, the concrete thickness is relatively thin, and these concaved parts could be easily perforated and could be readily utilized for horizonal drainage paths into the inside of the open-ended hollow pole, to accelerate the dissipation of the excess power water pressure generated around the pole. Thus, the short hollow pole type of RPP may be considered partially permeable. Ground response in the case of the short hollow pole with drainage holes may be analogous to the situation of sand compaction piles installed in soft clay (Asaoka et al. 1994). although the vertical drainage paths in the pole are not available.

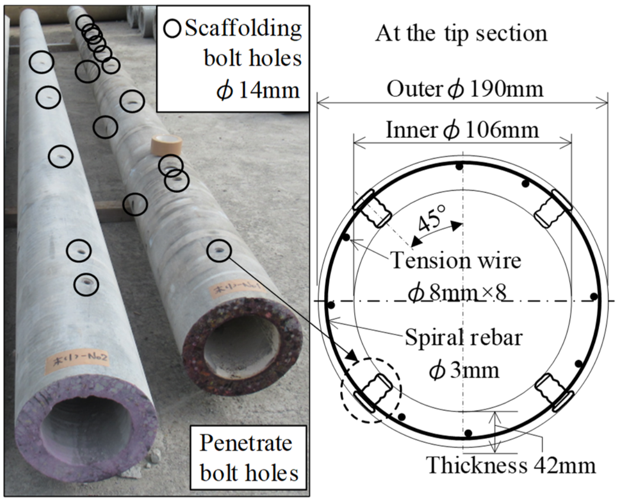


Fig. 5 A series of scaffold along the pole

According to the IPA recommendations about the applicability of press-in techniques per the range of SPT N value and penetration length for sheet piles and tubular piles (IPA, 2021), the standard press-in method can install sheet piles or tubular piles of say, 10m long, into the ground of SPT N vale less than 25 both for sandy soils and clayey soils. When SPT N values are more than 25, some driving assistance such as water jetting or augering is required.

The length of RPP is 6m or less. The maximum penetration capacity is governed by a piling machine used. Thus, the selection of the types of RPP and the method of pling becomes an issue to consider. The authors consider that it may be appropriate to classify the soil types into four.

(1) Very soft clayey soil (C1), SPT N value of 0-2

It is considered that the undrained shear strength of this type of soil is small and any type of RPP may be jacked in very soft clayey soils by the press-in method. In the long run, the perforated short hollow pole is beneficial for this type of soil, since the shaft resistance of RPP can increase with time in accordance with the excess pore water pressure dissipation with time.

(2) Soft clayey soil (C2), SPT N value of 2-4

It is considered that the undrained shear strength of this type of soil is higher, and the small diameter perforated short pile or semi-circular or quarter-circular plate may be selected. In some cases of larger SPT N value, it may require the rotary press-in method or a larger capacity piling machine. It may be useful to adopt the technique of surging during piling.

(3) Very loose sandy soil (S1), SPT N value of 0-4

Since the penetration resistance of very loose sandy soils is considered to be small, the short hollow poles or other types of RPP may be installed by the press-in method.

(4) Loose sandy soil (S2), SPT N value of 4-10

Since the penetration resistance is expected higher, the quarter-circular plate may likely be selected. In some cases, it may require a vibratory hammer. Thus, a chart is tentatively proposed in selecting an appropriate reinforcing member for a given soil condition, depending on soil type and the value of SPT N, shown in **Fig. 6**.

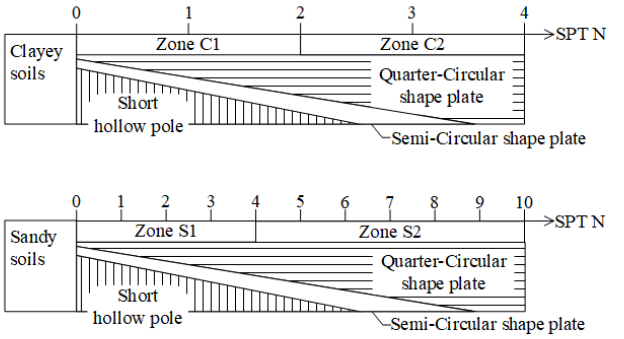


Fig.6 A tentative chart for selecting reinforcing members for various soil types

7. Field tests

Two field tests were conducted in housing projects.

7.1 TEST-1

The first test was conducted at a hilly area developed for a residential district. The main purpose of the first test was to examine whether commercially available piling machine is able to jack the reinforcing members made from the removed PC pole into the ground.

Typical Japanese houses are two stories, made of wood. Swedish sounding test is commonly adopted for foundation design for such houses in Japan. A nearby boring lot given in **Fig.7** indicates that beneath the thin surface layer, there exists the 4m thick layer of volcanic-origin clayey soil with SPT N value of 3 to 5, underlaid by a sand layer. **Figure 8** presents the results of the Swedish sounding test at the project site.

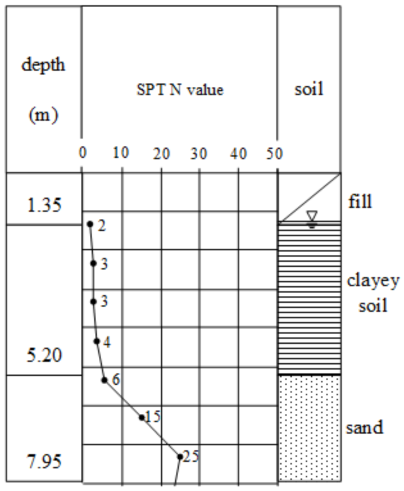


Fig.7 Soil profile near the first test site

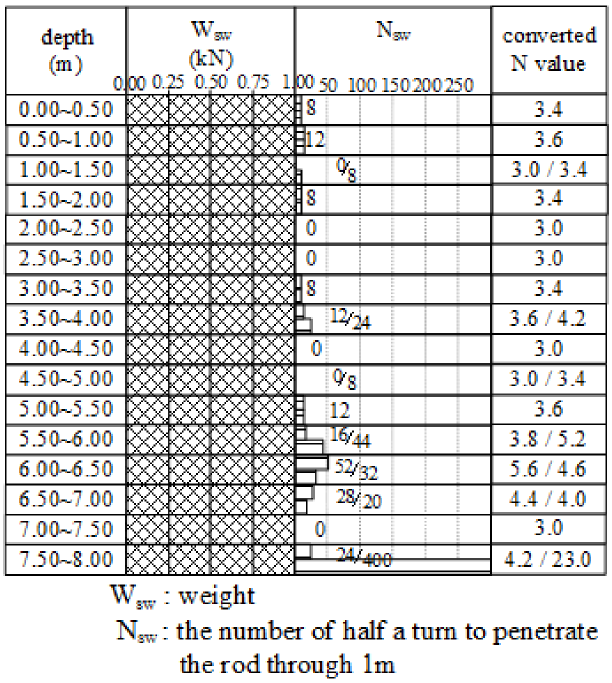


Fig.8 Results of Swedish sounding tests

Two static loading tests were conducted: one for 6 m long semi-circular shape plate and the other for 6m long short hollow pole. The piling machine used was Komatsu Padra BA100-2, of which nominal maximum jacking capacity of 130 kN. **Photo 5** shows the views of the test processes from pitching the reinforcing member into the piling machine to jacking the member into the ground. The experiences revealed that the pitching and jacking with the small piling machine went well without any problem with respect to mechanical and operational aspects.

Photo 5 Views during pitching and jacking

The first static jacking test (press-in method) was carried out on the semi-circular shape plate. The plate was penetrated to a depth of 4.8m with the applied load of 69.6 kN. The applied load was maintained for 30 min. and no further settlement was observed. The next jacking test was on the short hollow pole. The pole was loaded up to 112 kN at a depth of 3.7m, which is nearly the maximum capacity of the piling machine.

The experiences of the TEST-1 confirmed that the commercially available piling machine is able to jack the reinforcing members into the ground.

7.2 TEST-2

The second test was conducted at an area developed for a residential district near a small river. The main purpose of the second test was to examine whether the smaller piling machine (ybm GI50C-HT α 20K, with the nominal capacity of torque of 2.6～19.5kN-m and the nominal vertical press-in capacity of 39.2kN), the most commonly used for chemical soil improvement, is able to perform the rotary press-in method for the short hollow poles. The press-in method using the piling machine used in the TEST-1 was also carried out on the short hollow poles for comparison.

The test site was at a housing project with an area of 7m x 14m. The half of the area was used for the rotary-press-in method (area A) and the other half for the press-in method (area B).

A nearby boring lot given in **Fig.9** indicates that beneath the thin fill layer, there exists a 1.4m thick layer of clayey soil with SPT N value of 7, underlaid by a gravel bed with SPT N value of about 30.

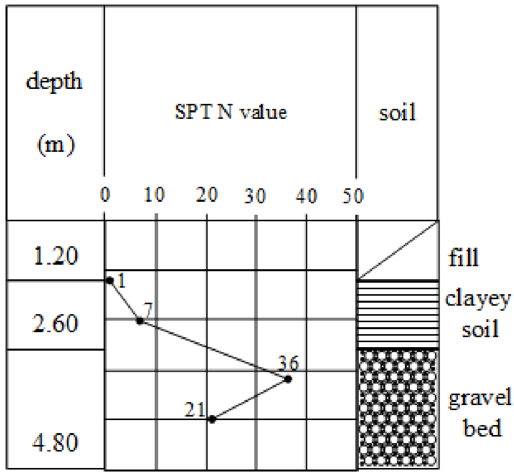
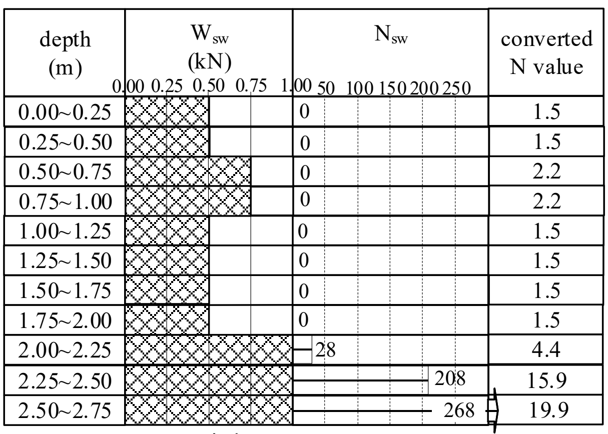


Fig.9 Soil profile near the second test site



W_{sw} : weight
N_{sw} : the number of half a turn to penetrate the rod through 1m

Fig.10 Results of Swedish sounding test

The results of Swedish sounding tests at the test site are given in **Fig.10.** It shows that there is a soft deposit with the converted N value of less than 2.5, underlaid a stiff deposit with the converted N value of more than 15 from -2.25m measured from the ground surface.

The rotary press-in method was carried out at the area A. To perform the rotary press-in method, two arrangements were made: the rotary arrangement of a steel rod of 41mm diameter inserted at the upper part of the short hollow pole, and the cutting edges arrangement at the toe of the pole, as are shown in **Photo 7**. It was confirmed that the rotary press-in method with the smaller piling machine can install the short hollow pole to the depth of the expected gravel layer of -2.25m.

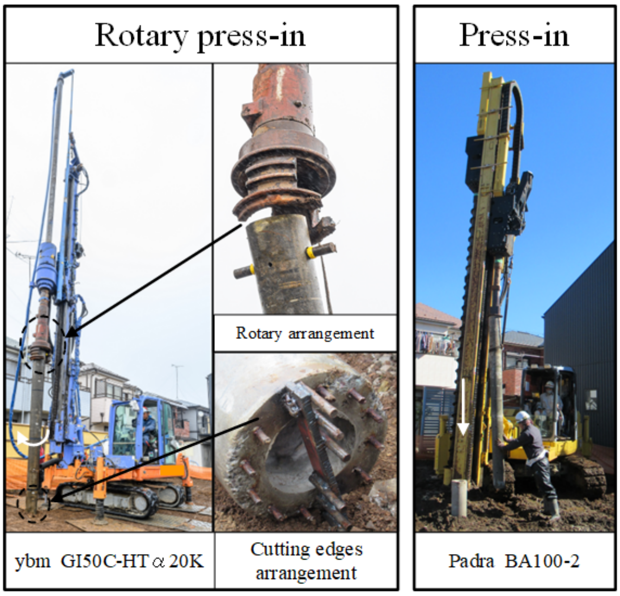


Photo 7 Views of rotary press-in method and press-in method

The press-in method was performed at the area B, in which 23 short hollow poles were statically jacked in by Padra BA 100-2.

For foundation design for small houses, the recommendations by the Architectural Institute of Japan (AIJ, 2021) are frequently referred to. The recommendations adopt the empirical relationships between SPT N value and Swedish sounding test results, as

$N = 2W_{sw} + 0.067N_{sw}$ for sandy soil (1)

$N = 3W_{sw} + 0.050N_{sw}$ for clayey soil (2)

AIJ states that the ultimate bearing capacity is the sum of the toe resistance and the shaft resistance. AIJ recommends the following equations for the ultimate toe resistance, Rp, as

$Rp = 200NAp$ for sandy soil (3)

$Rp = 6cAp$ for clayey soil (4)

where N is given by either eq. (1) or eq.(2), and $c = (45W_{sw} + 0.75N_{sw})/2$.

The ultimate shaft resistance, R_f, is calculated by

$$R_f = D\Sigma(\tau_d L_i)\ \pi \quad (5)$$

where D: pile diameter, τ_d: shaft resistance (τ_d = c for clayey soil, τ_d = 10N/3 for sandy soil), and L_i: length of each layer.

Figure 11 shows the load-settlement curves for the selected short hollow poles. The piling machine pre-augered the ground down to -0.5m before the vertical load was applied.

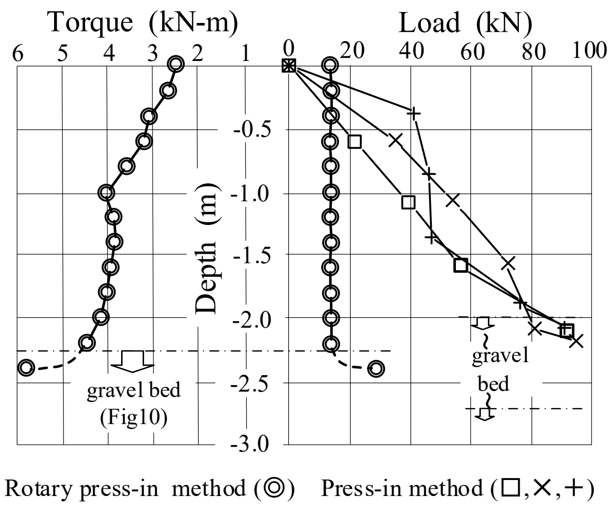


Fig.11 Load/Torque -settlement curves

The three load- settlement curves of the press-in method show a similar trend, reaching the maximum applied load of about 80 kN or slightly more at the gravel layer. It should be noted that Fig. 10 was taken from the Swedish sounding test data at the area A. According the Swedish sounding test results at the area B, the gravel bed is located at a slightly lower depth than that at the area A. The value of 80kN is very close to the ultimate bearing capacity of 79kN estimated by the AIJ method with the Swedish sounding test results.

Figure 11 also plots the data of the rotary press-in method, indicating that the required vertical loading capacity of the piling machine for the rotary press-in method can be significantly smaller than the those of the press-in method.

It was confirmed from the TEST-2 that the rotary press-in method successfully installed the short hollow pole to the bearing layer, with much smaller vertical press-in capacity than those of the press-in method.

8. Possible installation methods

For RPP installation, various options can be considered for selecting in installation methods such as press-in method, pre-boring method, rotary press-in method, high frequency vibratory hammer, provided that the method is acceptable for a construction site in the residential district. The paper reported successful applications of the press-in method and the rotary press-in method for RPP reinforcing members.

9. Concluding remarks

This paper introduced a recent attempt of an electric power company to reduce CO_2 emissions by shifting the re-cycle option to the re-use option in dealing with removed electric PC poles. The paper described the feasibility of the removed PC pole for a ground reinforcing member. The results of two field tests at the housing projects, using the press-in method and the rotary press-in method were presented to confirm the high potential of re-use option of the removed PC pole for reducing CO_2 emissions in piling practice.

10. Acknowledgements

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