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Development History of SILENT PILER (Part 3): Development of PPTS

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1. Outline of PPTS

In the Press-in Method, the installation process can be observed by monitoring the static load required for pressing-in the piles into the ground. This feature has been paid attention to since shortly after the launch of the first press-in machine (SILENT PILER) in 1975 (Kitamura, 2017), in an expectation that the monitored information can be used for verifying the performance of every single pile. To turn this expectation into reality, efforts have been made both from academic and practical points of views. Academically, a joint research with the University of Cambridge was commenced in 1994, based on the awareness of Mr. Akio Kitamura (Executive Chairman of GIKEN LTD.), and has been continued up to present (Ishihara & Haigh, 2018), providing the accumulation of the reliable experimental data and the understanding on the soil-pile interaction mechanism during press-in piling. Practically, we started to develop the technique of utilizing the data monitored and recorded during piling (piling data) in 2007, and have continued collecting the piling data in actual piling sites as well as in our test fields or experimental facilities.

The practical use of the piling data was conceptualized in the illustration shown in Fig. 1 in 2008 (Ishihara et al., 2008). The examples of the press-in piling data are the vertical jacking force, rotational jacking force (or torque), penetration depth, time, rotation number and so on. The piling data can be obtained automatically by a system equipped in a press-in machine. The obtained piling data are supposed to be utilized mainly in three ways; selecting piling conditions, estimating subsurface information and estimating the performance of piles.

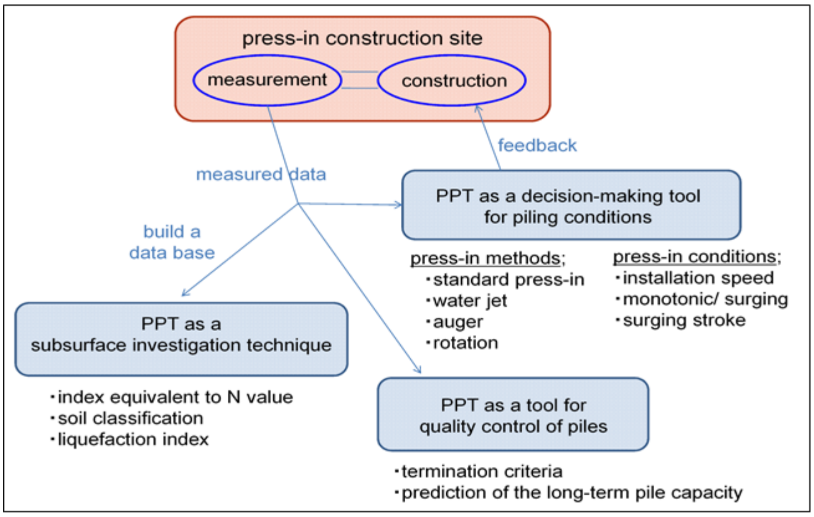


Fig. 1. Concept of the use of press-in piling data

The selection of piling conditions refers to the selection of an adequate penetration technique (Standard Press-in, Press-in with Water Jetting, Press-in with Augering or Rotary Cutting Press-in) and the selection of adequate values for press-in conditions such as the rate of penetration or extraction, rotation number, displacement of penetration or extraction and so on. An automatic operation of the press-in machine is a typical example of this application.

The estimation of subsurface information refers to the estimation of information related with the ground at the base of a pile which is being pressed-in. It is expected to improve the reliability of the termination control of the press-in piling work and to provide an objective material for judging the necessity of adopting another penetration technique or modifying the embedment depth of piles.

In the estimation of the performance of piles, it is expected that a capacity or a stiffness of a pile in a vertical or a horizontal direction is estimated from the piling data. This will make it possible to assure the quality of each pile while mitigating the impact of additional time and cost required for confirming the performance of piles based on the conventional load testing methods.

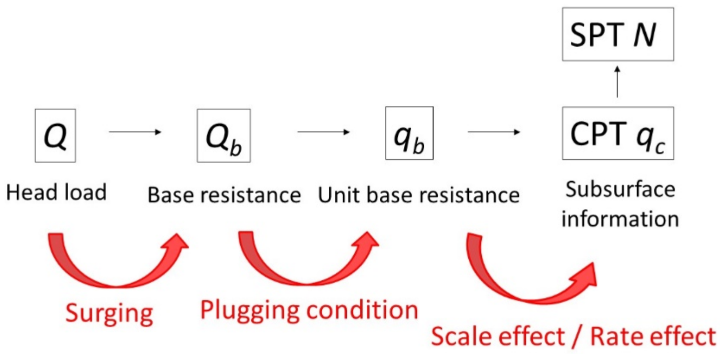
In the early stage of the development of this technique, the focus was mainly on the estimation of subsurface information, and this technique was called as PPT (Pile Penetration Test), in analogy with the technical terms of CPT (Cone Penetration Test) and SPT (Standard Penetration Test) that refer to the subsurface investigation techniques. After that, as the expansion of the focus into the automatic operation of the piling machine, it was renamed as PPT (Press-in Piling Total) System and was registered with NETIS (New Technology Information System) (MLIT, 2014) as No. SK-170006-A in 2017. The methods of estimating subsurface information from the press-in piling data were assessed by IPA-TC2 and summarized into a technical material in Japanese in 2017 (IPA, 2017). At present, the automatic operation technique of PPTS is equipped in the latest machines of Press-in with Augering, while the subsurface estimation techniques of PPTS are equipped in the latest machines of Standard Press-in, Press-in with Augering and Rotary Cutting Press-in.

2. Estimation of subsurface information

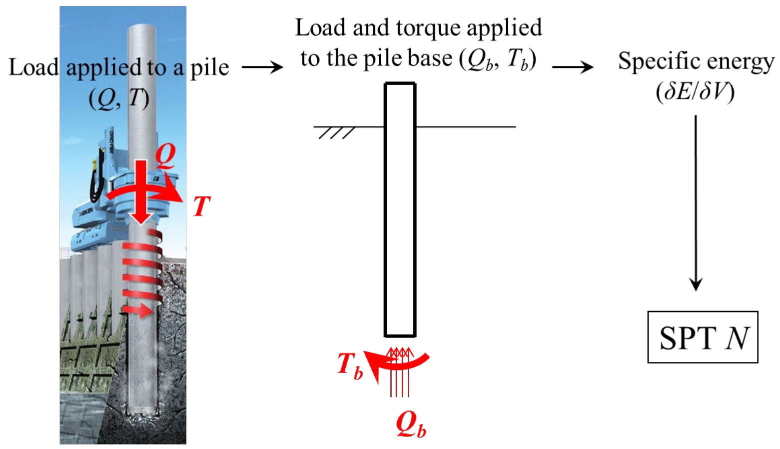
In Standard Press-in, a pile is installed with a static jacking force without the use of any installation assistance (such as water jetting or augering). It follows that the process of the penetration of a pile is similar to that of a cone in CPT. Taking advantage of this similarity, Ishihara et al. (2009a, 2009b) demonstrated that the base resistance Q_b, measured by the load cell in the base of the closed-ended pile, and the shaft resistance Q_s, obtained by subtracting Q_b from the head load Q, can be converted into CPT cone resistance (q_c) and sleeve friction (f_s) by considering the scale effect (White & Bolton, 2005) and the rate effect (Finnie et al., 1994; White et al., 2010; Bolton et al., 2013) on Q_b. Subsequently, the soil type and SPT N can be estimated based on the methods developed by Robertson (1990) and Jefferies & Davies (1993) respectively. The instrumentation on piles for measuring the base resistance became no longer necessary when Ogawa et al. (2012) confirmed that the base resistance can be obtained as the difference between the two values of the jacking force recorded when the pile base passes a certain depth for the first time and for the second time in one cycle of surging.

Regarding Press-in with Augering, two methods to estimate SPT N values were proposed by Ishihara et al. (2013), based on the knowledge in the field of rock drilling. The first one uses the proportional correlation between the parameter $T_b/(d_c)^\gamma$ and the unconfined compressive strength of a rock (Nishimatsu, 1972; Fukui, 1996; Fujimoto, 2005), where T_b is the torque on the auger head, d_c is the depth of cut (ratio of downward to rotational velocity) and γ is a constant. The second method adjusts the parameters used in the technique of MWD (Measurement While Drilling) (JGS, 2004) to link the resistance on the auger head with SPT N values.

In Rotary Cutting Press-in, SPT N values are estimated by assuming a proportional correlation between the SPT N values and the energy (δE) required for deforming a soil below the pile base by a volume of δV (Ishihara et al., 2015). This assumption is based on the knowledge of the linear correlation between the Specific Energy (= $\delta E / \delta V$) in rock drilling and the unconfined compressive strength of the rock (Hughes, 1972; Li & Itakura, 2012). The calculation of the Specific Energy requires the information of the resistance on the pile base, not on the pile head. Ishihara et al. (2015) proposed a method of decomposing the load and torque applied to the pile head (Q, T) into base and shaft components (Q_b, Q_s, T_b and T_s), based on the assumptions that both Q_b and T_b are expressed by the base stress (q_b) and that the frictional stress on the pile shaft is shared by Q_s and T_s in proportion to the ratio of vertical to rotational velocity (Bond, 2011).



(a) Standard Press-in



(b) Rotary Cutting Press-in

Fig. 2. Processes of estimating subsurface information from piling data

The processes of estimating SPT N from the piling data in Standard Press-in and Rotary Cutting Press-in are summarized in Fig. 2.

3. Automatic operation of the press-in machine

When operating a press-in machine, the values of the press-in parameters such as the rate of penetration and extraction, the displacement of penetration and extraction, the flowrate of the water jet, the rotation number of the auger head and so on are controlled so that the piling operation is progressed smoothly while the resistance acting on the pile being pressed-in is maintained to be sufficiently smaller than the sum of the reaction forces. In the older versions of the automatic operation system of the press-in machine, the values of all the press-in parameters were determined by the operators themselves, and the press-in machine functioned "automatically" as specified by the operator. Expecting that the process of determining and specifying the values of the press-in parameters can also be automated by utilizing the information estimated from the press-in piling data, the collection of the piling data at construction sites were started in 2007, and much effort has been made to develop a program for this new automatic operation. The program for Press-in with Augering has been put into practical use since 2013.

The comparison of the existing automatic operation and the new (PPTS) automatic operation is shown in Fig. 3 (Ishihara, 2018). In the new automatic operation, press-in piling data such as the penetration depth, the vertical and rotational jacking force and the inclination of the press-in machine are utilized to estimate the piling state (the state of interlocking with the previously installed pile, the extent of plugging inside a casing of the augering device, and so on) and the ground condition at the pile base (SPT N for soils or the unconfined compressive strength for rocks). Based on the estimated information, adequate values for the press-in parameters are determined and fed back to the press-in machine. As a result, the efficiency of the piling work can be improved while the accuracy of the piling work is secured. With the use of the PPTS automatic operation, a trend has been confirmed that the more the ground condition varies with depth, to a greater extent the duration for the pile installation is reduced. Several case studies have shown that the reduction of the pile installation in Press-in with Augering was around 30% on average in the actual piling sites that have typical ground conditions containing gravels or varying with depth (Ishihara, 2018; JPA, 2020).

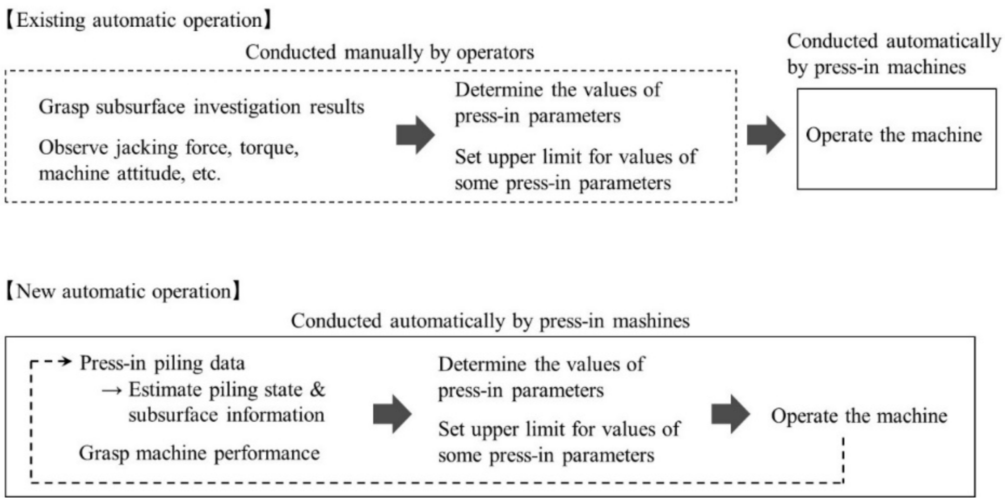


Fig. 3. Comparison of existing and new (PPTS) automatic operation system for press-in machines

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