STUDY ON DEVELOPMENT OF THE PILE PENETRATION TEST SYSTEM BASED ON PRESS-IN CONSTRUCTION DATA

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ABSTRACT: In the Press-in Method, the piling technology, the piling machine jacks a pile into the ground by a static force using the reaction force derived from the previously installed piles. This technique allows the piles to be installed with less noise and vibration, and in addition saves the room required for the piling work, with the small hydraulic piling machinery and its construction system using no temporary works. Since this piling method enables the piles to be installed without excessively disturbing the soil around the pile, it is possible to obtain information about the ground conditions through monitoring the jacking force during installation and extraction. This feature of the Press-in Method suggests the possibility of utilizing the piles as a tool for grasping the ground conditions. Accordingly, the concept of PPT, Pile Penetration Test, is induced, and this paper introduces the PPT system by providing a clear explanation of it and arranging the present situation and awaiting solutions to develop the system. The PPT system is composed of four aspects; press-in construction site, PPT as a decision making tool for piling conditions, PPT as a tool for quality control of piles, and PPT as a subsurface investigation technique. Among these four aspects, ‘press-in construction site’ is essential to this system, for it functions in the system as the source of the PPT data. The other three aspects are all related to the interpretation of the obtained PPT data, and are expected to be of practical use both in construction sites and in geotechnical academic fields. These four aspects of the PPT system suggests as many research phases, which are discussed in detail in this paper. The system is eventually expected to enhance the benefits of construction works and contribute to producing more validity and accountability of the construction project, on the ground of its advantage of obtaining, supplementing and renovating the subsurface information in every press-in construction site all over the world.

KEYWORDS: press-in, pile penetration test

1. INTRODUCTION

1.1 Background

The Press-in Method is the pile installation technique using hydraulic jacking force. This technique allows the piles to be installed with less noise and vibration compared with other piling methods. It also saves the room required for the piling work, with the modern small hydraulic piling machinery and its construction system using no temporary works (Figure-1.). These advantages have promoted the Press-in Method to be accepted as one of the available piling methods in the urban area worldwide.

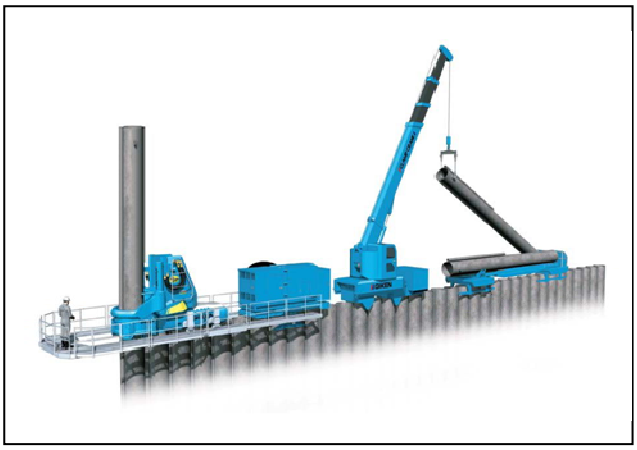

Figure-1. The Press-in Method

In the Press-in Method, the piling machine jacks a pile into the ground by a static force using the reaction force derived from the previously installed piles. Since the pile displaces the soil during the installation, the pressed-in pile is classified as the displacement pile, but its performance is supposed to be different from the other displacement piles and non-displacement piles (A. Jackson, 2007.).

The Press-in Method allows the pile to be installed without excessively disturbing the soil around the pile. This makes it possible to obtain information about the ground conditions through monitoring the jacking force during the installation and extraction. It follows that the piles being pressed-in can serve as a tool for the subsurface investigation technique, PPT (Pile Penetration Test), in the same way as the CPT and SPT are widely used in this field.

PPT is expected to be expansive, as it can be conducted simultaneously with the installation work, and as the testing doesn't interfere with the procedure of the conventional press-in construction work. PPT is supposed to serve as a decision making tool during the press-in construction process. It is also referred to as another advantage of PPT that it provides or renovates the ground information in every press-in construction site all over the world. In other words the PPT system is expected to contribute to enhancing the benefits of construction works by providing the subsurface information of the construction sites.

1.2 Objectives

Since the PPT system is expected to be effective in decision making process during the construction process or to have the advantage of providing the subsurface information to increase benefits of construction work, the ultimate goal of this research is expressed as developing and utilizing the PPT system. However, as this system is a new concept in the geotechnical research field, the objectives of this paper should be firstly to provide a clear explanation about the PPT system, by arranging the four related research phases involved; management of the construction site (construction and measurement), measuring method, interpretation of the measured data, and utilization of the subsurface information.

The second objective of this research is to grasp the present situation, and to abstract and specify the awaiting solutions, as to the related techniques in developing the PPT system. The existing state and problems of the press-in construction technique, measuring technique, and the data analysis technique are highlighted.

2. Outline of Pile Penetration Test (PPT)

The concept of PPT is explained by dividing it into four aspects (Figure-2.).

The most significant aspect of PPT is the 'press-in construction site'. This aspect functions in the PPT system as the source of the PPT data. The measurement is carried out at the same time as the construction work. It should be noted that the measurement methodology is planned to be carried

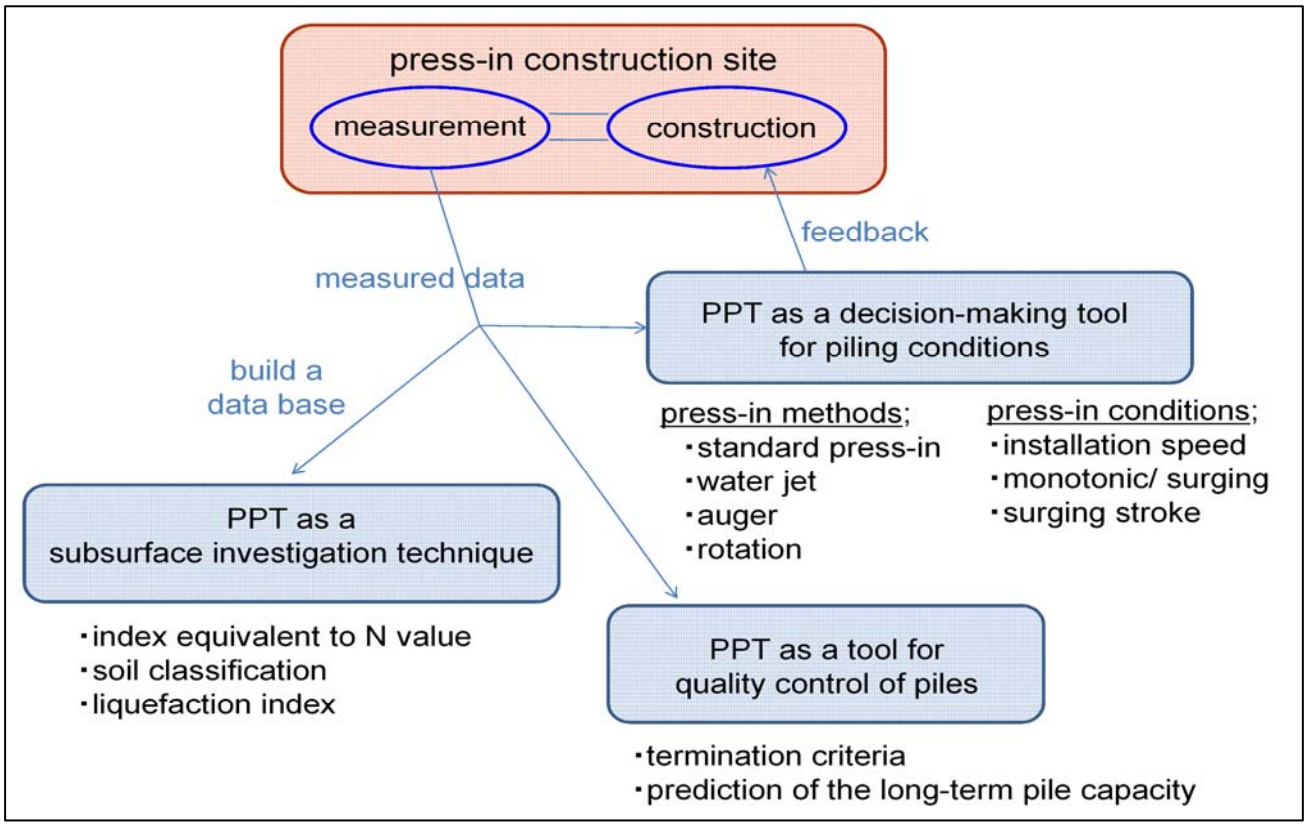

Figure-2. The PPT System

out in the simplest manner where the necessary measured items are provided and the adequate accuracy of the measurement is assured.

The aspect of 'PPT as a decision-making tool for piling conditions' is one of the other three aspects of the PPT system. The 'piling conditions' means the conditions to be established in the press-in construction, and consists of 'press-in methods' and 'press-in conditions'. 'Press-in methods' refers to the variations of the press-in construction method, such as standard installation, installation with water jetting system, installation with integral augering system. The 'press-in conditions' include the installation speed, the installation procedure (monotonic installation or surging - the repetitive combination of installation and extraction), the surging stroke (installation and extraction length in one surging) and so forth. All of these are supposed to reduce the jacking force required for the installation (extraction). This is important from the viewpoint of construction workers, because the installation goes smoothly and the efficiency of the construction work is enhanced if the jacking force is controlled smaller.

Considering the completed piles as products, to control the quality of them is also an essential aspect of the PPT system. Since the Press-in Method is relatively a new piling method, subjects such as pile capacity, pile stiffness, termination criteria have yet to be fully understood. This situation has restricted the usage of the pressed-in piles to the temporary constructions. However, recent researches have revealed that the pressed-in piles show better performance in the light of geotechnical engineering, which would promote its use as a bearing pile foundation. Instead of the conventional method of load test, the aspect of 'PPT as a quality control tool for completed piles' is aimed to give a simpler method, saving time and money, to predict or confirm the performance of the completed piles.

Representative examples of the subsurface investigation are Corn Penetration Test (CPT) and Standard Penetration Test (SPT). Except the dynamic CPT, CPT is the static penetration test, where the ground resistance during the installation of the penetrating rod is measured. SPT on the other hand is the dynamic penetration test, and the number of blows necessary to install the rod by a certain depth is measured. Since Press-in Method is to install piles by the static jacking force, it is expected to serve as a static penetration test. 'PPT as a subsurface investigation technique' suggests the possibility for a pile being pressed-in to be used as a penetrating rod of the penetration test. Therefore PPT is expected to be one of the subsurface investigation techniques, providing index equivalent to N value, or showing the classification of the soil around the pile.

3. Specifications for developing the PPT system

3.1 Management of construction site

In the construction site, the workers' concern is how they manage to install piles as exactly and efficiently as possible. What should be paid attention to the most in order to realize the exact and efficient pile installation is to control the jacking force smaller. The greater jacking force induces the inclination of the pile and the piling machine, or transformation of the pile. Such inclination and transformation of the pile and the piling machine degrade the quality of the completed piles or delay the construction work.

As discussed in 3.3.1, one of the validities of PPT is to provide a certain criteria to select the adequate press-in methods and conditions, and to contribute to reducing the jacking force during installation and extraction. The construction site is essential to the PPT system, because it serves the environment where the measurement and construction can be conducted simultaneously. However, if the validity of PPT in the light of reducing the jacking force is not fully understood by the workers, they would find some difficulty in having enough incentive to carry out the measurement in their construction work.

At this moment, as the PPT system is in its trial stages, the construction site where PPT can be carried out is restricted. The conditions of the construction site required for conducting PPT as a trial are the enough construction period, simplicity of the construction work (using no subsidiary measures for installation such as water jetting or augering), and constant communications with workers. It is necessary to make trials of PPT in these kinds of construction sites and improve the PPT system from the perspectives of 3.3, so that the system attains to provide the appropriate design and construction methodologies.

To add to applying PPT in these restricted construction sites, it is essential to expand its practice to all the other press-in construction sites. Three measures are proposed to be taken in this light; firstly the education on the PPT system should be introduced in the construction site management. The education aims to let the workers develop their understanding of the validity of PPT for the better piling technique, the better assurance of the performance of the completed piles, and the larger contribution to the construction industry through providing the investigated ground information. The second measure is to compile a worker's manual of PPT and offer the workers sufficient information. This is supposed to remove the workers' concern, which is produced partly by the lack of knowledge about the procedure, that the measurement interferes their work and that the PPT plays a negative role from their perspective.

Practical thinking may point out that, whatever

contributions PPT may make toward the workers or the society, PPT would not be accepted in the construction site, if the measurement itself takes time and makes trouble. To simplify the measuring method of PPT is the third measure to be taken.

3.2 Measuring method

Since the PPT requires the measurement to be carried out simultaneously with the construction work, the measuring method should be in the simplest manner to meet the objectives of PPT. The solution to this demand at present is to introduce the PC monitoring system into the construction site (Figure-3.). The press-in machine is equipped with the measuring instruments, and the measured data are transmitted to the PC connected to the press-in machine as PPT data. The PC can display the measured PPT data on the spot, so that the workers can utilize the PPT data immediately in their construction work.

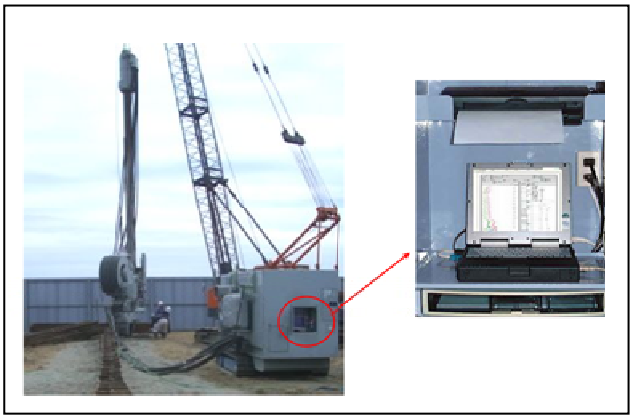

Figure-3. PC Monitoring System

The basic measured items in the PC monitoring system are jacking force (installation force and extraction force), embedment depth of the pressed-in pile, and the inclination of the press-in machine. Other items such as base and shaft resistance of the pile, pore water pressure around the pile, vibration of the pile during installation, are excluded in this monitoring system, because these items cannot be measured by equipping the press-in machine with the measuring instruments (they should be equipped in piles to be pressed-in). It is possible that the PPT system require these additional items to be measured as well, or make it necessary to improve the precision of the measurement, for these points are helpful in developing its aspects of quality control of the completed piles and the subsurface investigation technique.

3.3 Interpretation of the measured data

3.3.1 Decision-making tool for piling conditions

From the viewpoint of construction workers, it is desirable that the jacking force during the installation and extraction should be smaller. Reduced jacking force makes the installation process smoother, so that the construction work can be exact and efficient.

Varieties of causes can be listed to explain the increase of jacking force during installation and extraction. Plug (clogging of the soil inside or around the pile), set-up (time effect due to dissipation of excess pore water pressure, thixotropy, creep), the resistance in the interlock, and the ground condition, are considered to be the primary factors. To cope with these factors, several ‘piling conditions’, composed of ‘press-in methods’ and ‘press-in conditions’, have been devised and being put into practice in the construction site. The examples of ‘press-in methods’ are;

・attaching a water jet system to the standard hydraulic piling machine,

・attaching an auger system to the standard hydraulic piling machine,

・adopting a different type of hydraulic machine which can rotate the pile.

On the other hand, ‘press-in conditions’ are exemplified by the followings;

Table-1. Press-in Conditions

with/without interlock	monotonic /surging	stroke conditions
with	surging	manual
without	surging	manual
with	surging	manual
with	surging	automatic (350-150)
without	surging	automatic (350-150)
without	monotonic	automatic (800-0)
with	surging	automatic (450-150)
with	surging	automatic (450-150)
with	monotonic	automatic (800-60)
with	monotonic	automatic (800-60)
with	monotonic	automatic (800-60)
with	monotonic	automatic (800-60)

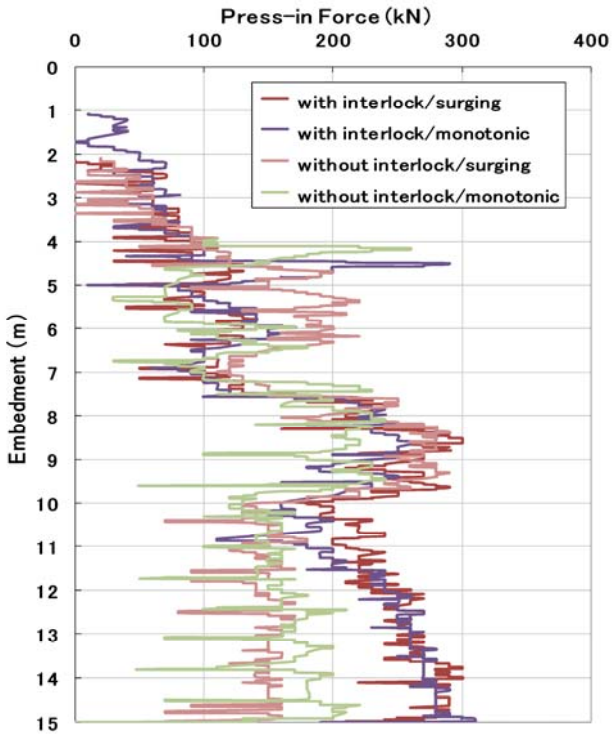

Figure-4.

・moving the pile up and down repeatedly (‘surging’, as opposed to ‘monotonic installation’),

・a set of installation and extraction stroke during surging,

・installation and extraction speed.

PPT is supposed to provide a certain standard to select the adequate ‘press-in method’ and ‘press-in conditions’.

Explanation of PPT as a decision-making tool for the press-in conditions is given below, by showing a specific case of PPT. PPT requires that firstly the pile is installed by monotonic installation, with the standard press-in method, in order to select the press-in methods. If the pile proves to be installed within a certain jacking force in this case, the standard press-in method is chosen as the press-in method in the construction site. However, in the following case, as will be common for some time to come, the boring data was given in advance, so the process to select the press-in method was based on the boring data, not on PPT. When the press-in method was settled, several press-in conditions were established (Table-1.). Then the piles were installed based on each press-in condition, and the PPT data was acquired. Combined data (Figure-4.) showed two decisive points:

・Surging has no influence on the jacking force.

・Resistance in interlock appears at 11m, and increase continuously as the pile is installed deeper.

The above information was available to the workers in the site where the data had been acquired, and helped them select the adequate press-in conditions there.

The problem is that it is required for some person to set up the press-in conditions first and then to combine the PPT data, abstracting the necessary information and feeding it back into the better press-in conditions. This process has to be standardized in a simple manner so that the effective decision can be made by all the workers in every construction site.

3.3.2 Tool for quality control of completed piles

The press-in construction method has so far focused mainly on steel sheet piles, which are usually used for temporary constructions. This is due to the disadvantage of the Press-in Method, that the piles can be installed only in the soft ground, or that the

long-term performance of the completed piles such as pile capacity and vertical displacement is not clearly understood. However, as the press-in construction machines and the steel piles have been improved, the pressed-in piles are beginning to be accepted as the foundations of the permanent structures.

This trend has made it necessary to develop a series of theory to predict the performance of the pressed-in piles. The domestic situation is that no specific formula or theories are presented in any design manuals or handbooks. In the academic field, the methodology to predict the capacity of the pressed-in piles is studied (D. J. White & A. D. Deeks, 2007.). This prediction is based on the CPT data of the ground. In other words, the present researches into the performance of the pressed-in piles are aiming to link the long-term performance of the pressed-in piles with the CPT data.

On the other hand, there could be another approach to predict the long-term performance of the pressed-in piles. This is one of the three conclusions the PPT system provides. The jacking force during the installation of the pressed-in piles is expected to be utilized to estimate the capacity or the stiffness of the completed piles. The methodologies of this estimation have yet to be developed. In addition, this aspect of the PPT system is supposed to require precise measurements, which leads to complicate the measurement process. However, as the load tests carried out for assuring the performance of the piles of the other construction methods consumes much time and money, the quality control by the PPT system is expected to get rid of this disadvantage of the load tests carried out in the construction sites.

3.3.3 Subsurface investigation technique

The PPT system is expected to provide ground information in press-in construction site, for the press-in piles can be considered as the penetrating rod used in CPT and SPT technique. Most of the recent researches aim to link CPT or SPT data with the ground resistance during installation. On the contrary, the PPT system proposed in this paper shows a unique approach to utilize the information such as pile resistance directly as PPT data to provide the ground information. This approach brings about a variety of research topics, which are required to account for the relationship between ground information and PPT data. In this item, the examples of research topics are introduced, with the specific results attained at the moment.

The ground resistance measured during the press-in installation is supposed to be connected with N value of the ground. In this perspective, it is expected that PPT can provide a certain index which corresponds to N value. Figure-5. shows the property of ground resistance and base resistance during the installation and extraction of a tubular pile.

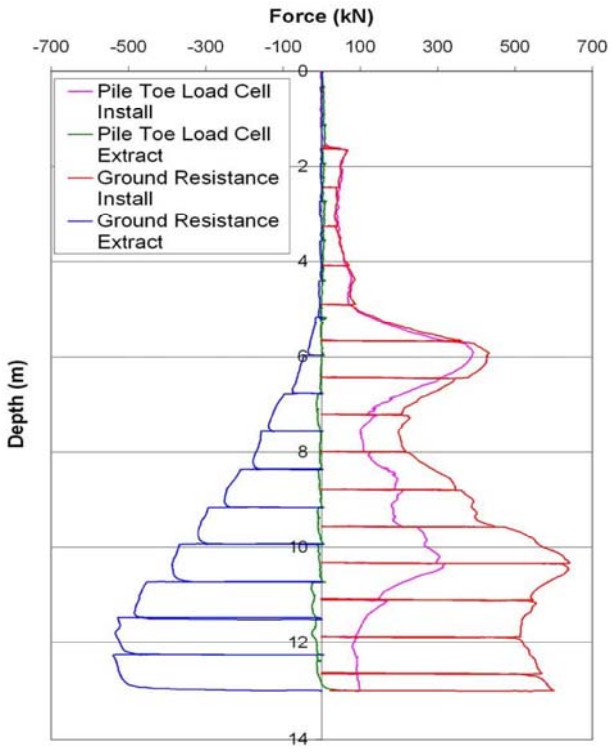

Figure-5.

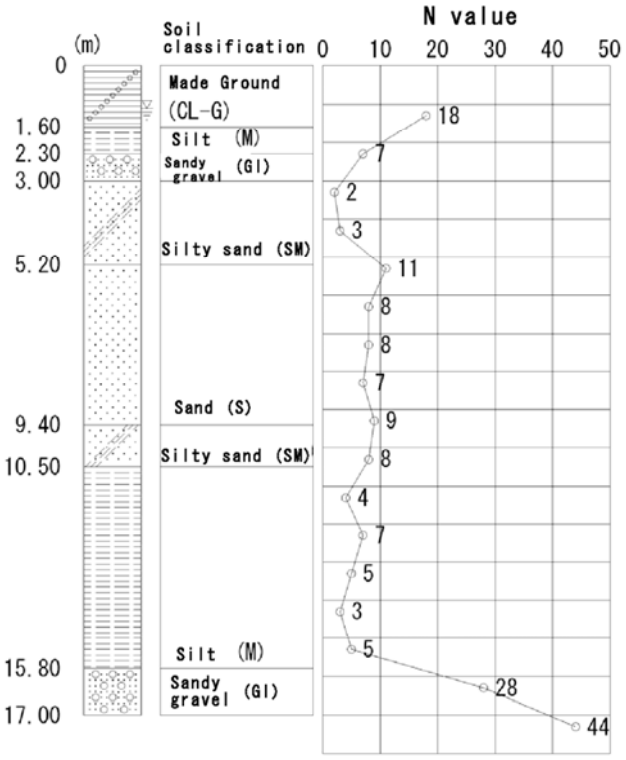

Figure-6. SPT Data

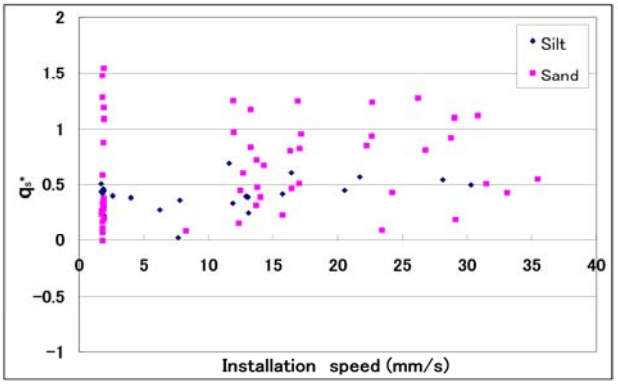

Figure-7.

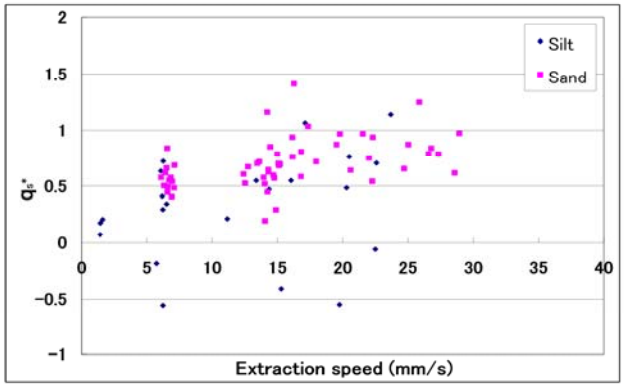

Figure-8.

Comparing it with the result of SPT (Figure-6.), the base resistance in PPT shows some similar tendency with N value in SPT. Further researches should be made with the variation of pile types, to compare PPT data and N value. Formula to predict the jacking force from N value deserves to be studied as well.

To develop the methodology to classify the soil materials is another research subject. One of the methodologies being studied at the moment to classify the soil material around the pile is to arrange the correlation between the installation (extraction)

velocity and the unit shaft resistance applied to the pile. As is explained in 3.3.2, during the installation

and extraction, the ground resistance is reduced due to the decrease of the effective stress of the soil around the pile. This decrease is caused by the excess pore water pressure produced during the installation and extraction of the pile. The excess pore water pressure is expected to correlate with installation and extraction velocity. Therefore it is possible that the velocity and the unit shaft resistance have some correlation. On the other hand, it is considered that different type of soil shows different tendency in producing excess pore water pressure, because of the difference in the coefficient permeability. Results of this analysis, based on the data acquired in the installation and extraction of the 318.5mm tubular pile, are shown in Figure-7. and Figure-8 (J. Shiwa, et al., 2007.). Here, q_s* is the non-dimensional coefficient which is supposed to correspond with the friction coefficient between the pile and the soil. At this moment the results are not conclusive enough to classify the soil. Further researches should be carried out, using varieties of piles such as sheet piles and other tubular piles with different diameters.

Another methodology that is expected to be

effective is to classify the soil material based on the proportion of shaft resistance to base resistance. This idea derives from the research on soil classification using CPT data (P. K. Robertson, 1990.). Similar approach can be made in the case of PPT as well, if either the base resistance or the shaft resistance is measured.

It is also pointed that PPT is expected to provide the criterion of assessing the possibility of liquefaction of the ground in the press-in construction sites. As the pile displaces the soil around it and the soil mass changes its volume during installation and extraction, excess pore water pressure generates as a result (it could be either positive or negative). The positive excess pore water pressure reduces the effective stress of the soil and therefore decreases the jacking force during the installation and extraction. The excess pore water pressure is supposed to be influenced by depth, particle diameter, installation speed, etc. By monitoring these items during the installation and extraction of the pile, PPT can serve as the liquefaction index to suggest the possibility of liquefaction in and near the construction site.

3.4 Utilization of the subsurface information

Among the four aspects of the PPT system explained in this article, ‘PPT as a subsurface investigation technique’ shows that the PPT system has a universal application, beyond the territory of press-in technology. The subsurface information provided by the PPT system is expected to be utilized in all the other construction designs in the future, as the data are accumulated and the methodologies to interpret them are developed.

Since the PPT data are acquired only in the press-in construction site, it is necessary to consider the impartiality and transparency of the obtained information. In this light, it is effective to build up the database of the subsurface information by PPT, providing the accessibility to the information. Procedures to be followed for utilizing the database should be as simple as possible. On the other hand, it is also necessary to draw a clear line which distinguishes the gratis information from the onerous information.

The advantages of the subsurface information obtained by PPT are that the information can be obtained in every press-in construction site and that the information can be supplemented or renovated every time the press-in constructions are conducted.

The aspect of PPT that it provides or renovates the ground information in every press-in construction site all over the world adds the new benefit to the construction work itself. This will influence the economic assessment of the construction project, producing more validity and accountability of the projects.

4. Conclusions

The concept of the PPT system was introduced in this paper. The PPT system is composed of four aspects; press-in construction site, PPT as a decision-making tool for construction conditions, PPT as a tool for quality control of piles, and PPT as a subsurface investigation technique.

In order to realize the PPT system, several research phases were pointed out. Management of construction site requires an educational approach, in addition to the development of simple measuring method which does not interfere with the construction procedure. In the interpretation of the measured data, three research phases were introduced, and each phase has not completely

studied yet at the moment. ‘Decision-making tool for press-in conditions’ requires trial-and-errors in the construction site by preparing a manual and applying it to each construction site. ‘Tool for quality control of completed piles’ and ‘subsurface investigation technique’ involves varieties of geotechnical research topics. Both experimental and theoretical researches should be carried out into these phases.

The PPT system is expected to provide the advantage of obtaining, supplementing and renovating the subsurface information in all the press-in construction sites all over the world. To construct a subsurface information database is essential to assure the impartiality and transparency of the information. This will enhance the benefits of construction works, and contribute to producing more validity and accountability of the construction project.

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