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Development of New-type Steel-Pipe Methods for Urban Renewal Projects

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Abstract

For urban renewal projects pushed forward now in various fields, Nippon Steel Corporation developed methods of construction newly in the field of pipe-piles, with "TN-X Method" to be good at high support in the field of building and "Gyro-Press Method" to be good at a self-run type turn press fit method of construction in the field of building a revetment. Because of the establishment of an execution management method newly to secure execution reliability in these development and confirmed it by a loading test about the characteristic of bearing capacity, this reports on the results and introduces the applicability of a regular employee method in real execution examples.

1. Introduction

In recent years, in order to revitalize Japan's economy, urban renewal projects have been undertaken to enhance the charm and international competitiveness of "cities"—which are a major source of the country's vitality. In megalopolises, such as Tokyo and Osaka, the focus is on rebuilding affluent and comfortable cities that exhibit economic vigor. In local cities, the major emphasis is on harmonious coexistence between mankind and nature, community development to ensure an enriched, and comfortable life, and the redevelopment of the central areas of urban districts, etc. Under those conditions, Nippon Steel has been developing new pile methods that utilize the advantages of steel pipe piles for pile foundations to better contribute to such urban renewal projects. The company is already marketing the TN-X method designed for urban construction projects and the Gyro-Press method designed for river projects.

This paper describes the circumstances leading up to the development of the TN-X and Gyro-Press methods and their characteristics. It also describes the results of experiments carried out to confirm the performance of pile using those new methods. In addition, examples of construction projects in which the TN-X or Gyro-Press methods were actually used are presented to demonstrate their effectiveness.

2. TN-X Method[1)]

2.1 Aim of development and outline of the TN-X method

In urban seaside areas, airport terminals and industrial warehouses, etc. have been actively constructed to enhance the functions of existing airports and seaports in large cities so as to reinforce their international competitiveness. Despite the massive and heavy nature of these buildings, the use of this pile method that affords a large bearing capacity enables a reduction in the number of piles required. Such an approach helps to cut both construction costs and terms, and thus contributes to the efficient development of social infrastructure.

During the construction of urban buildings, in view of the problems of noise and vibration, the steel pipe pile method (inside boring & pile end consolidation method) has been mainly used. However, this method does not provide sufficient bearing capacity for massive and heavy buildings. Therefore, Nippon Steel has created the TN-X method that permits the building of an enlarged and consolidated pile at the pile end some 1.25 to 2 times larger in diameter than the pile. (The shape of the enlarged and consolidated pile was not provided for in the past.) In the TN-X method, an excavating machine equipped with opening and closing wings as shown in **Photo 1** is used to excavate the ground, and a enlarged and consolidated foundation is built at the pile end as shown in **Photo 2**. The enlarged and consolidated foundation and the pile are formed as one unit to pro-

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(a) Opening wing (b) Closing wing

Photo 1 Excavation head

Photo 2 Enlarged pile end

vide a large bearing capacity. The ground is excavated by either the inside-boring method shown in **Fig. 1** (a) or the pre-boring method shown in Fig. 1 (b). The TN-X method has the following features.

(1) The enlarged and consolidated pile end, the optimum size of which can be selected according to the in-situ ground conditions, etc., combined with a steel pipe pile as one unit provides a bearing capacity up to about three times that of the conventional method.

(2) Since the TN-X method uses steel pipe piles, it permits reducing the amount of excavated soil that occurs in the construction work.

(3) The TN-X method offers an excellent cost performance ratio since it increases the flexibility of design (because the diameter of the

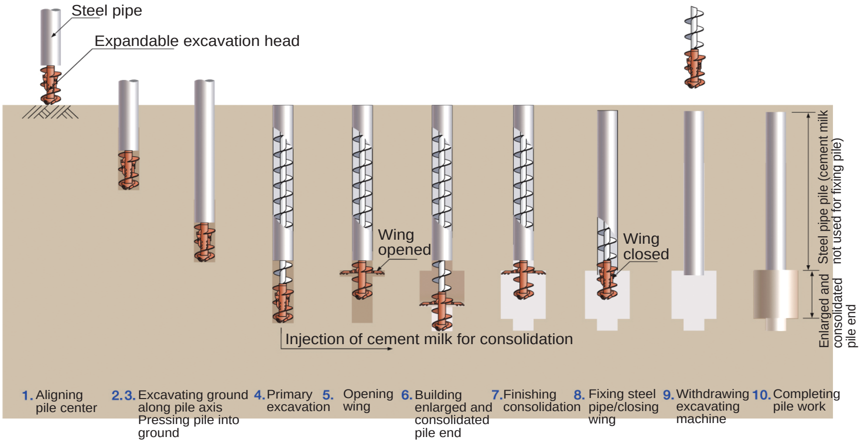

Fig. 1 (a) Inside-boring method

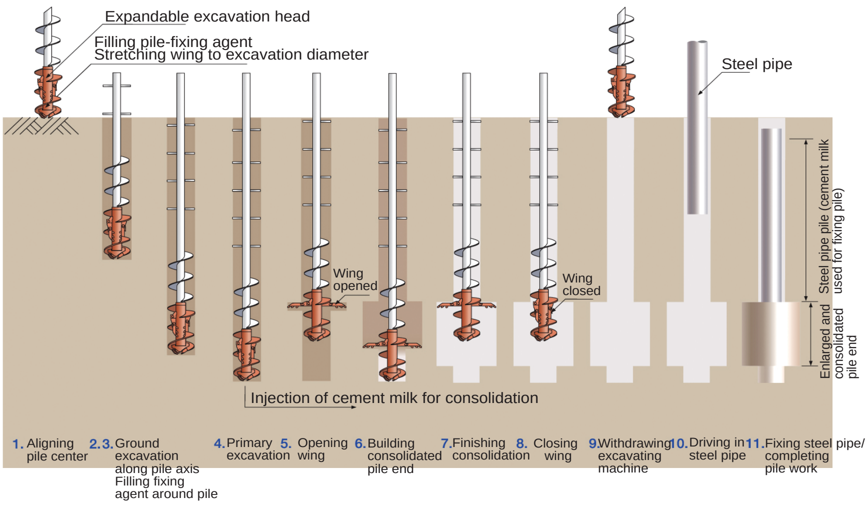

Fig. 1 (b) Pre-boring method

enlarged and consolidated pile end is variable), improves the working efficiency, and reduces the amount of excavated soil, amongst other factors.

(4) The construction monitoring system developed specially for the TN-X method ensures highly reliable construction by building enlarged and consolidated foundations and driving in the steel pipe piles.

2.2 Outline of construction work management

In the TN-X method, in order to ensure positive building of the enlarged and consolidated pile ends, which is most important from the standpoint of securing the required bearing capacity, the number of opening wings used and the number of soil agitations are adjusted according to the hardness of the bearing ground. In addition, in order to control the shape and quality of enlarged and consolidated pile ends, a hydraulic system for opening/closing the excavation wings was adopted. By controlling the amount of oil supplied from the system, it is possible to quantitatively grasp the opening wing diameter while the excavation head is in the ground. An excavation head monitoring system as shown in **Photo 3** was also introduced. This system permits monitoring of the excavation head opening/closing wing diameters that cannot be seen directly in the ground, with an accuracy of 1 cm. It also permits monitoring the excavation depth, excavation speed, and cement milk injection rate, etc. on a real-time basis so that the operator can control them all from his console.

2.3 Example of load test

By applying the construction management technique described in 2.2, the TN-X method has improved the construction reliability of enlarged and consolidated piles. To confirm the bearing capacity of a TN-X pile, a load test on a pile 900 mm in diameter was carried out in Sashima-gun, Ibaraki Prefecture. As a result, it was confirmed that the TN-X pile had a maximum vertical bearing capacity about three times that of a conventional steel pipe pile.

The outline of the load test is given below. The pile tested was a steel pipe pile (SKK490: 900 mm in diameter, 27 mm in thickness and 52.0 m in length). It was driven into the ground using the inside-boring method, and an enlarged and consolidated pile end having a diameter 1.5 times that of the pipe pile was built in the supporting layer. The ground consisted mainly of alternate layers of silty clay and fine silty sand having an N-value of 10 or less to a depth of about 20 m, a layer of fine sand having an N-value of 50 or more at a depth from 20 m to 27 m, and a layer of clayish silt having an N-value of about 5 at a depth from 27 m to 51 m. The steel pipe pile was driven into the ground with a layer of gravel having an N-value of 50 or more to a depth of 51 m to 60 m as the bearing ground. The test pile was so long that it was considered that the skin friction would be considerable and hence the test load would become excessive. Therefore, friction-reducing material was used in the intermediate layer. In the load test, the multi-cycle step loading method specified by the Japanese Geotechnical Society was used.

Of the load test results, the load-displacement relationships are shown in **Fig. 2** and the axial force distributions are shown in **Fig. 3**. With loading steps of 2,000 kN, the test was carried out in six cycles (2 steps per cycle). In the sixth cycle, the eccentricity of the pile top became so large that the application of load was stopped. At that point, pile displacement was measured as 163 mm at the top and 81 mm at the bottom. Thus, the amount of pile displacement at the bottom was less than 10% of the pile diameter—the reference displacement for second-limit-resistance. In the present load test, the maximum load applied to the pile was 24,000 kN at the top and 18,219 kN at the bottom. The second-limit-resistance is considered to be higher than the value at the pile bottom. When the maximum applied load was evaluated in terms of bearing capacity at the bottom of the consolidated pile, the average N-value was 61. Therefore, the coefficient of bearing capacity of the pile toe was about 209. The results of load tests carried out in the past, including those of the present one, were statistically processed. Based on the processing result, the bearing capacity coefficient in the formula for calculating bearing capacity of the pile toe was determined to be 198.

2.4 Example of application in actual work (Nishiura Warehouse)

As an example of the application of the TN-X method, a scene of the Nishiura Warehouse under construction is shown in **Photo 4**. This work was carried out to expand the warehouse capacity of Tokyo Port in order to cope with ever-growing logistics. The pile length

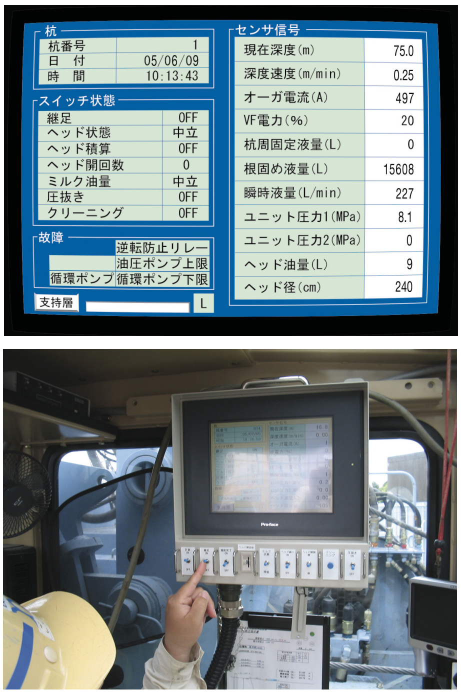

Photo 3 Sentaneye system example

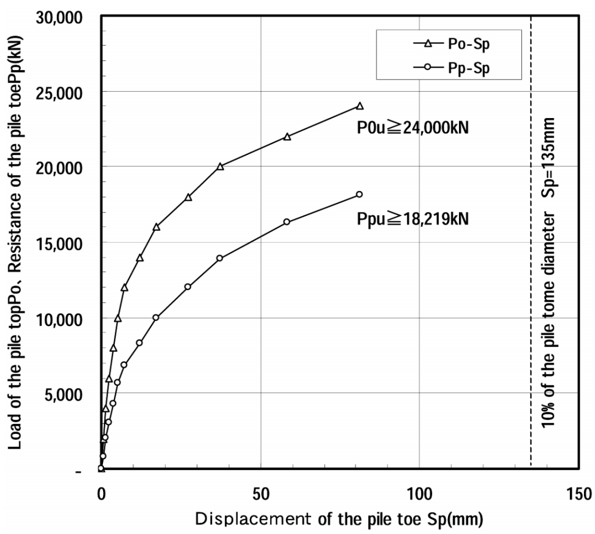

Fig. 2 Load-displacement relationship

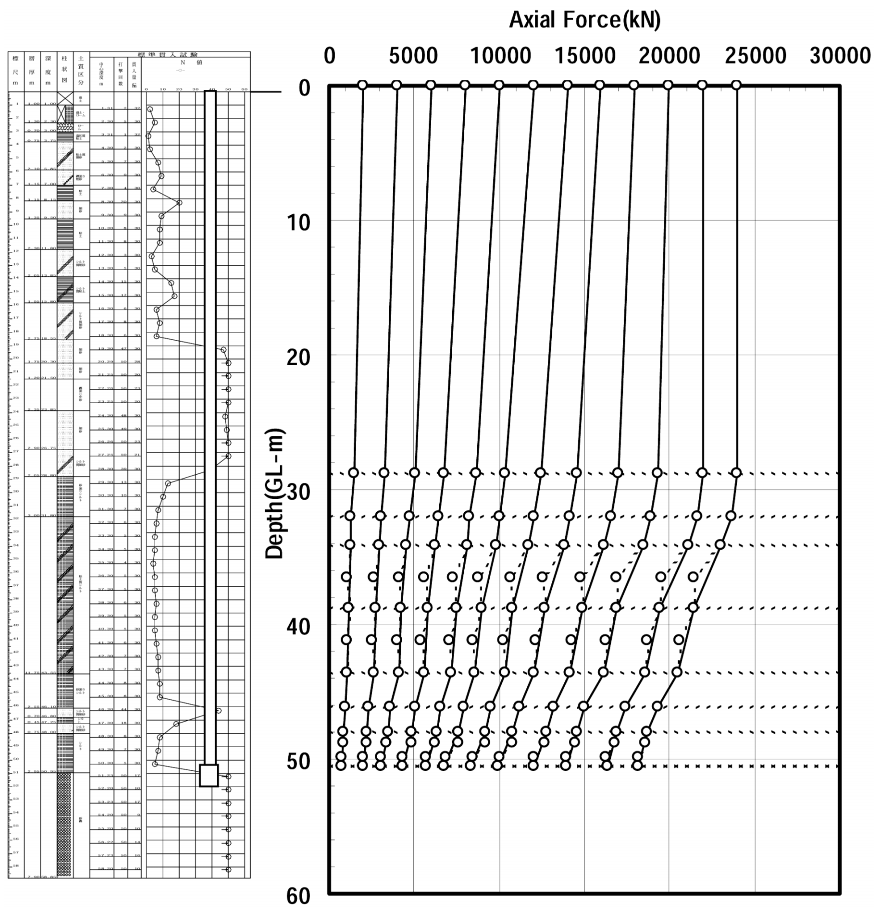

Fig. 3 Distributions of the axial forces

Photo 4 TN-X construction site example

was about 40 m. Since the construction site had a deposit of soil subject to liquefaction down to some 16 m from the earth's surface, the bending moment caused by horizontal load was substantial. Because of this, the planned competing method required two piles per column.

With the TN-X method, which features a large bearing capacity and high flexural rigidity of the steel-concrete composite construction enabled by arranging steel pipe piles provided with projections on the inside, only one pile was required per column. By adopting the inside-boring method, the TN-X method could reduce the amount of soil excavation to about 20% of the pile volume. In addition, the large bearing capacity made it possible to reduce the total number of piles required. As a result, the TN-X method shortened the term of construction by about 70% as compared with the competing method.

At the construction site, in order for Nippon Steel to confirm the precision of the enlarged and consolidated foundation built, a borehole sonar (manufactured by Tokyo Soil Research) was used to measure the hole diameters. The borehole sonar is a device which is inserted into a hole provided in a pile to measure the hole shape, etc. from the form of a reflected elastic wave. When the concrete interior is excited, a significant reflected wave occurs at the boundary between the enlarged and consolidated pile end and the ground. Therefore, a P-wave was excited in the pile circumferential direction and the reflected wave was received. By so doing, the consolidated foundation shape was measured at the cross sections and in the depth directions shown in **Fig. 4**. The measurement results are shown in **Fig. 5**. Although there are several problems that remain to be solved (e.g., measurement error), it can be seen that the prescribed shapes (consolidated foundation radii) were obtained at almost all cross sections. Thus, the high precision of the consolidated foundation built by the TN-X method employing the excavation head monitoring system was confirmed.

3. Gyro-Press Method[2, 3)]

3.1 Aim of development and outline of the Gyro-Press method

In recent years, as part of urban renewal, efforts have been made to enhance the functions and improve the earthquake resistance of

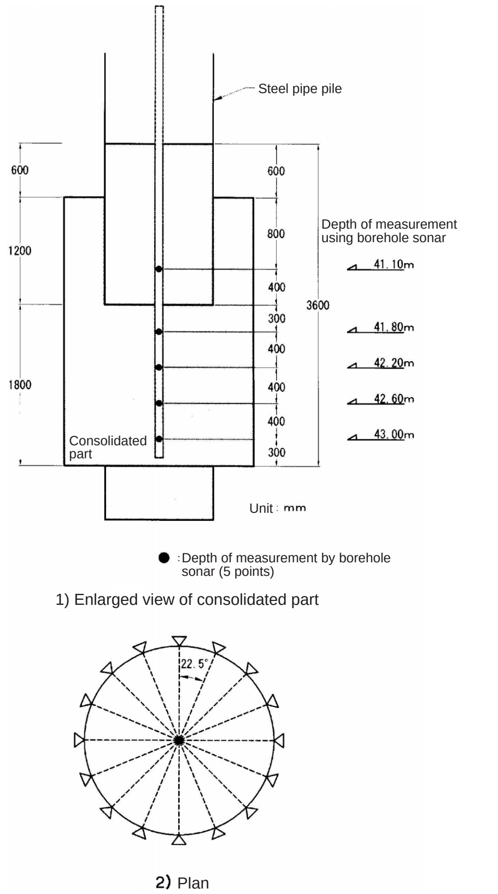

Fig. 4 Measured points

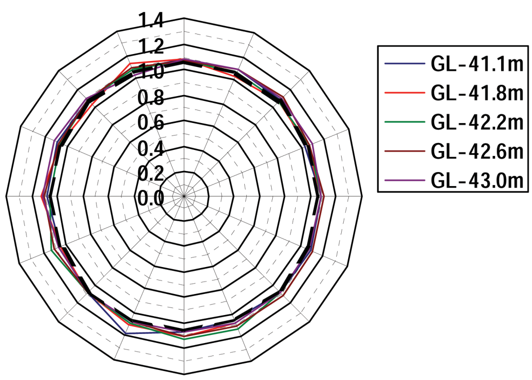

Fig. 5 Diameter of test results

various civil engineering structures, such as roadside retaining walls, river revetments and building foundations, in order to slow down the progress of their deterioration and functional decline and to provide against natural disasters. In many cases, however, executing revetment reinforcement works, road expansion works, etc. in urban areas involves a number of difficult problems. For example, it is subject to various limitations, including (1) confined construction sites, (2) interference with existing structures, and (3) control of noise and vibration.

Under such conditions, in order to reduce the working space and cut the cost of construction, Nippon Steel developed the Gyro-Press method to make use of the newly fabricated construction machine that is capable of rotating and pressing in a steel pipe pile provided with a cutting blade at the front end (**Photo 5**). In the Gyro-Press method, as shown in **Fig. 6**, the rotary press (gyro-press) grabs a steel pipe pile which has already been pressed into the ground and uses the resistance of that pile as the reaction force to press another steel pipe pile into the ground without producing noise and vibration. In this way, the gyro-press presses in steel pipe piles one after another to build an upright steel pipe pile wall. In this method, the cutting blades that are fitted to the front end of each steel pipe pile turn and cut the ground and obstacles. Therefore, it is necessary to select an appropriate number of cutting blades of appropriate hardness according to the ground and obstacles at the construction site. The salient features of this method are as follows.

(1) The rotary cutting mechanism enables the method to be applied to all ground conditions, including gravel layers containing cobblestones, bedrock and other obstacles.

(2) The construction machine used is compact and lightweight. In addition, since the machine securely grabs a steel pipe pile which has already been pressed into the ground during the work, the possibility of the machine overturning and pile eccentricity is minimized, allowing for very precise construction work.

(3) The levels of noise and vibration produced during construction are low. In addition, since the depth of soil cut is limited to that corresponding to the cutting blade thickness, minimal soil is excavated. Thus, the method has minimal impact on the environ-

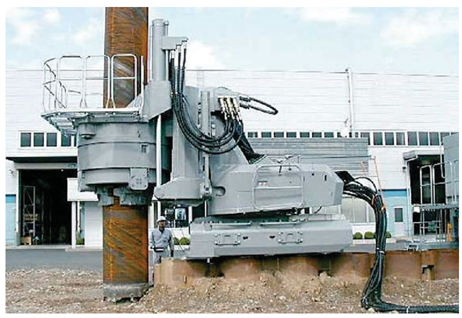

Photo 5 Gyro-pressing machine

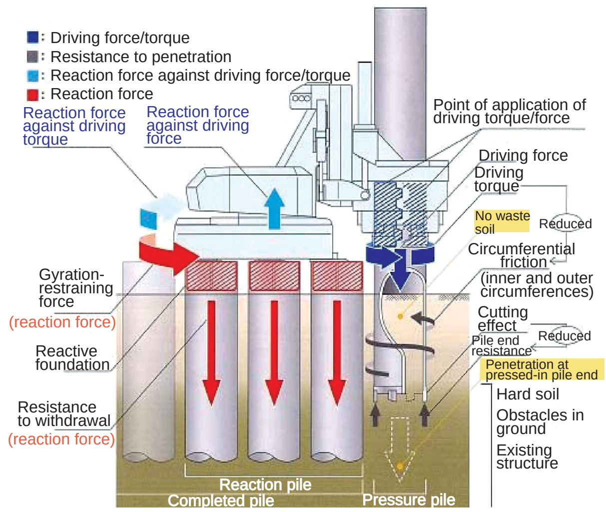

Fig. 6 Gyro-press mechanism

ment.

(4) The method permits continuously driving in inclined piles, such as raking piles and front bearing piles.

(5) Since the method allows for free combinations of pile diameter, pile length and pile arrangement, it is possible to select the optimum and most economical pile structure according to the specific purpose.

3.2 Outline of construction management

In the Gyro-Press method, as described above, the rotary press grabs a steel pipe pile which has already been pressed into the ground and uses its reaction force to press another steel pipe pile into the ground to build an upright steel pipe pile wall. In actual construction work, a monitor as shown in **Photo 6** is used to control not only the pile-driving pressure and torque, but also the horizontal and vertical precision of the piles. In addition, construction data about individual steel pipe piles is accumulated and analyzed to improve the reliability of construction using this method.

3.3 Horizontal loading test

Concerning the horizontal bearing capacity of piles pressed into the ground by the Gyro-Press method, a single pile 600 mm in diameter and a set of three piles of the same diameter were subjected to a horizontal loading test at Niida, Kochi Prefecture, to confirm that those piles had the same horizontal bearing capacity as piles driven in by conventional methods (percussion method, inside-boring method, etc.).

The load test was carried out as outlined below. Two patterns were tested: 1) two independent steel pipe piles (SKK490: 600 mm in diameter, 12 mm in wall thickness and 10,000 mm in length) were driven into the ground, one using the inside-boring method and one using the Gyro-Press method, and the test loads were applied to them in such a manner that they received the reaction force from each other, and 2) a set of three steel pipe piles of the same size was driven into the ground using the Gyro-Press method as shown in **Fig. 7** and subjected to the test loads. The soil profile at the test site is shown in **Fig. 8**. The soil down to a depth of about 10 m from ground level consisted mainly of a single layer of fine sand having an N-value of about 10. The test loads were applied using the multi-cycle, step application method specified by the Japanese Geotechnical Society.

The load test results are described below. In the test of the set of piles, the load began to decline after it reached 1,960 kN. Therefore, the test load was gradually decreased and the test was finished. In the test of the independent piles, at the fourth cycle of load application, the displacement of the pile driven into the ground by the inside-boring method became so large that it was considered impossible to continue applying load to the gyro-pressed pile. Therefore,

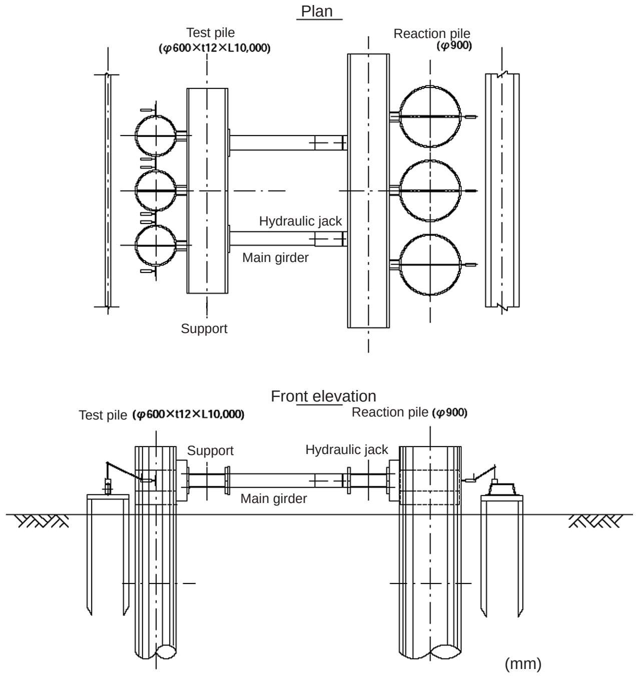

Fig. 7 Test equipment

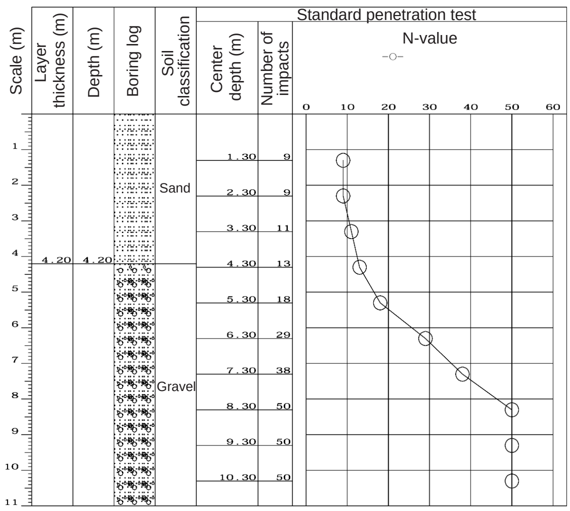

Fig. 8 Soil profile on site

Photo 6 Monitor of execution management

the inside-bored pile was fixed after the displacement reached 50 mm at the earth's surface, and the application of load to the gyro-pressed pile was continued until the fifth cycle, when the displacement reached about 0.1 D (60 mm). The load-displacement relationships obtained are shown in **Fig. 9**. For the set of piles, one-third of the load applied to it is shown as the load.

Fig. 10 compares the measured load-displacement relationships of the independent and combined piles with those calculated in accordance with the Specifications for Highway Bridges[4], the Guidelines of Road Earthwork[5], etc. The conditions for calculations are: (1) the formula of Hayashi-Chang shall be used to calculate horizontal displacements, (2) the average N-value used to calculate ground deformation coefficient Eo shall be assumed to be 10 from the soil profile, (3) the reference displacement shall be assumed to be 6 mm,

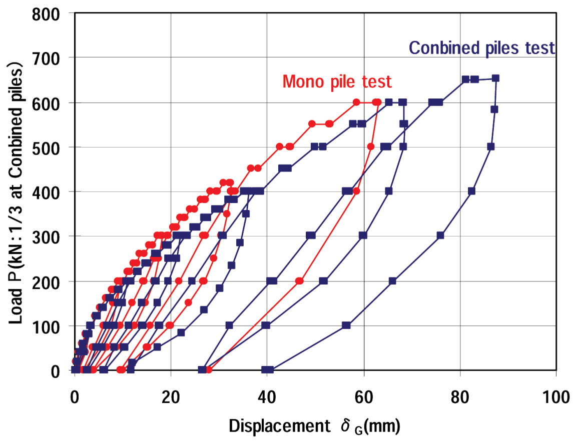

Fig. 9 Load-displacement relationship

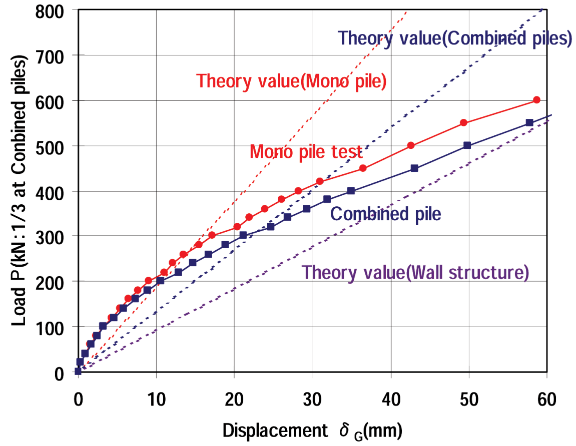

Fig. 10 Theory-test value relationship

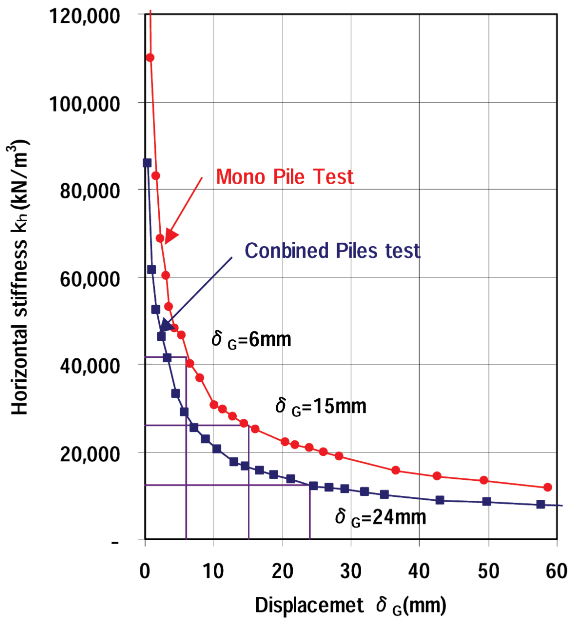

Fig. 11 Horizontal stiffness-displacement relationship

or 1% of the pile diameter, for the single piles and 24 mm, or 1% of the 3-pile foundation width, for the set of piles, and (4) for the set of piles, consideration shall be given to group pile efficiency μ (μ = 1 – 0.2 [2.5 – L/D] = 0.80 (where L is the pile center-to-center distance, and D is the pile diameter)); provided, however, that when calculating the design value for wall construction, group pile efficiency shall be ignored and a linear spring corresponding to the unit pile length shall be considered. The horizontal stiffness-displacement relationships obtained are shown in **Fig. 11**. In the figure, the relationships with the reference displacements are also shown.

To sum up the test results, 1) the horizontal stiffness coefficient of the single pile is larger than the design value, 2) the single pile and the pile set are nearly the same in horizontal stiffness when the displacement is within about 10 mm, but the horizontal stiffness per pile of the pile set becomes smaller than that of the single pile when the displacement exceeds 10 mm, and 3) the horizontal stiffness of the pile set is larger than the calculated value when the pile set is assumed as a wall and nearly the same as the pile design value when consideration is given to the effect of grouping piles. From these results, it is considered possible to design the horizontal stiffness coefficient of gyro-pressed piles in accordance with the Specifications for Highway Bridges . Similarly, it is considered that the horizontal stiffness coefficient of gyro-pressed piles as a wall can be designed in the same way as when one of the conventional methods specified in the Guidelines of Road Earthwork, etc. is used.

3.4 Example of construction

A scene from the Oyoko River Minamishisen revetment work is shown in **Photo 7**, and a scene from the Furukawa revetment work is shown in **Photo 8**. Both were carried out using the Gyro-Press method.

3.4.1 Oyoko River Minamishisen revetment work

Originally, this work was planned to secure the stream's channel by demolishing the existing revetment and building a new one. However, since the only space available for the construction work was a 4.0 m wide path for river management, the size of construction machines that could be used was limited. Therefore, in the work, the Gyro-Press method that permits penetration even of RC structures and carrying out pile work even in a confined place was adopted. In addition, the "non-stage method" in which a construction system for carrying, hanging and pressing in piles is installed on existing piles was employed. As a result, the revetment work using piles 800 mm across and 17.0 m long could be completed in about half of the term that would have been required if the conventional method using a temporarily erected pier was adopted.

3.4.2 Furukawa revetment work

This work was to renew the existing revetment. The construction

Photo 7 Gyro-press construction site example 1

Photo 8 Gyro-press construction site example 2

site conditions were tough: there were office buildings and piers of the Metropolitan Expressway along the river and no hinterland was available. Therefore, the revetment work was subject to various unfavorable conditions. For example, the work under the Metropolitan Expressway had to be carried out in an area with limited headroom (about 6.0 m in height) and a temporary pier as the footing for the construction machine could not be erected in the river because it would significantly reduce the cross-section area of the river during the construction work. Under those conditions, it was difficult to carry out the work smoothly using any of the conventional methods. Therefore, a construction machine sufficiently small in height was adopted. In addition, since it was necessary to break through the existing block revetment 4.9 m in height, a gyro-press equipped with an excavating device as a means of preventing the steel pipe piles from being blocked was employed. As a result, it was possible to install the steel pipe piles (1,000 mm across, 13.5 m long; jointed at four points) at a rate of one-half pile per day without causing the pipe interior to be blocked. The new method reduced the construction term to about two-thirds that of the conventional method.

4. Conclusion

It is considered that the TN-X method and Gyro-Press method as described so far are Nippon Steel's new products, and they will play an important role in urban renewal projects which are actively carried on today as they fully display their performance with improved reliability of construction management and new construction systems developed for space savings. The authors intend to continue our efforts to promote the new methods more widely and further improve them. They also plan to propose new pile structures that can be installed safely, speedily and economically even under severe working conditions in urban areas, thereby contributing to efficient development and maintenance of social capital.

Acknowledgments

The TN-X method was developed jointly by Nippon Steel and Tenox Corporation, and the Gyro-Press method was developed jointly by Nippon Steel and Giken Seisakusho Co., Ltd. The authors wish to express their deep appreciation to all the people concerned for their generous cooperation in the joint development of these new methods.

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