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Expanding Applications of the Gyropress Method™

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Abstract

Nippon Steel & Sumitomo Metal Corporation developed a novel driving method for steel pipe piles, the Gyropress method™, jointly with Giken Ltd. The method has accumulated experience of application to revetments for urban rivers, roads, etc. In the field of disaster prevention and construction of urban infrastructures, higher walls have been designed and piles are often required to be driven through hard soils and underground concrete structures. To respond to such needs, the pile diameter has been increased, drivability into hard grounds enhanced, and the applicability of the method expanded to the driving of bearing piles.

1. What is the Gyropress Method™

1.1 Outline of the method [1–3)]

The Gyropress method has been developed by Nippon Steel & Sumitomo Metal Corporation jointly with Giken Ltd. with a view to improving or renewing the foundations for river revetments and earth retaining walls for roads and other urban infrastructures, many of which are becoming aged especially in urban areas and requiring revamping or reconstruction.

Construction work in urban areas often has to be conducted under many restrictions such as (i) limited site space, (ii) interference in existing structures, and (iii) requirements of low noise and vibration. To overcome these issues, the Gyro Piler, which can install steel pipe piles by rotating and pressing (see **Fig. 1**) is applied, and, the cutting bits are attached at the tip of the pile (see **Fig. 2**). In addition, water is discharged from the tip portion of the pile as shown in **Fig. 3**. In order to reduce load on the machine during piling and shorten the work period. Moreover, to construct or revamp, it is sometimes necessary to take measures against earth flowing out through the gaps between piles, and depending on the soil conditions and the groundwater level behind the wall, equilateral angle steels are pressed into the ground to close the gaps (see **Fig. 4**).

An earth retaining wall is constructed following the steps illustrated in **Fig. 5**. Firstly, the Gyro Piler is mounted on the heads of formerly driven pipe piles, and it rotates and presses a steel pipe pile into the ground (parts 3, 4 and 5); Secondly, the Piler adheres to the pile being driven and climbs it; Thirdly, the Piler moves forward to the position of a subsequent pile (parts 6 and 7); lowers itself (part 8); takes in a new pile; and rotates and presses down the new pile (part 8 and parts 1 and 2). A retaining wall of steel pipe piles is formed by following the above steps sequentially while the piling machine moves on the heads of the piles already driven into the ground.

1.2 Advantages of the Gyropress method

The Gyropress method, adopting the unique piling method described in Section 1.1, has many advantages as follows:

(1) The Gyro Piler is supported on the heads of formerly driven pipe piles, uses them as the reaction piles for rotating and pressing down a new pile into soil, travels forward on them in the direction of wall construction, the reason for which no temporary basements are required, and piling work can be conducted at a congested area.

(2) The method causes little noise and vibration. The amount of water supplied at the pile tip is less than that of a water jet, and adverse effects on the surrounding environments are minimal.

(3) Since the rotation and the downward force are applied to the pipe pile through the pipe wall, pile driving is possible even

Fig. 1 Gyro Piler

Fig. 2 Steel pipe pile with end bits

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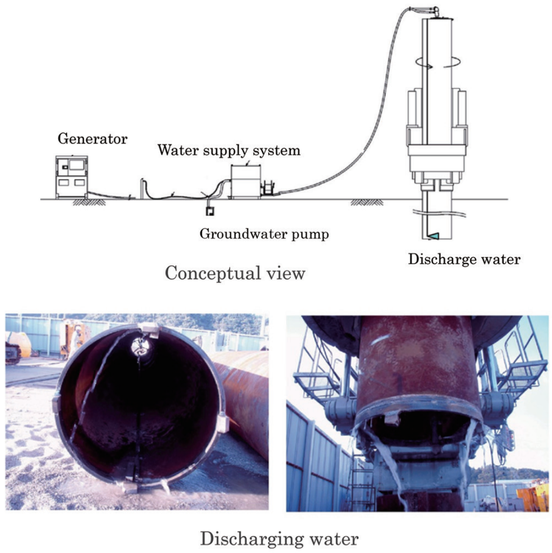


Fig. 3 Water supply system

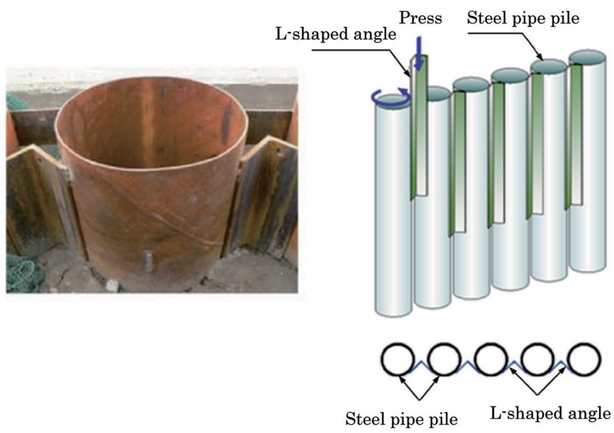


Fig. 4 Joints of steel pipe piles

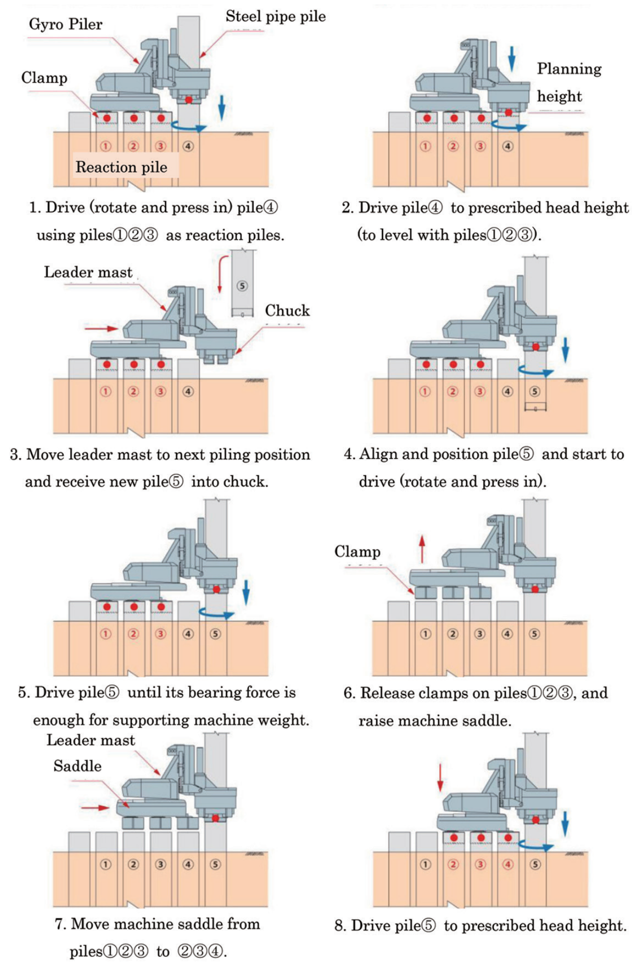


Fig. 5 Construction process

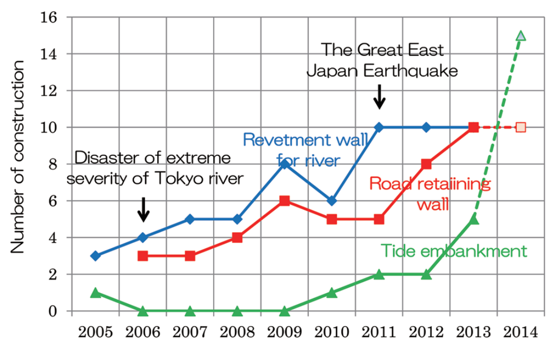


Fig. 6 Application references of Gyropress method

when the overhead clearance is limited, for instance, the work site is under a bridge or adjacent to a road or a railway in normal service.

(4) As no additional temporary structures are required and no surplus soil is discharged, the pile driving can be conducted at any time of the day, and the construction term can be shortened.

(5) Even if the soil is hard or there is an obstacle under the ground such as concrete structure, it can be penetrated by special cutting bits at the pile tip.

(6) The Gyro Piler can handle steel pipe piles 500 to 1 500 mm in diameter, which enables economical design according to wall height.

1.3 Application experience [4, 5]

Figure 6 shows the experience of use of the Gyropress method in different fields of application. Since its launch onto the market in 2004, it has been employed for constructing around 150 earth retaining walls for rivers and roads in urban areas, mainly for renewal purposes. Measures to prevent or minimize disasters have been taken throughout Japan since the Great East Japan Earthquake in March 2011 and the Basic Act for National Resilience in December 2013, and as a consequence, the method has been applied to an increasing number of reinforcements of river banks and construction of tide barriers. In addition, in preparation for the 2020 Tokyo Olympic and Paralympic Games, construction of many transportation infrastructures has begun in and around Tokyo, which naturally involves the construction of many revetments for road improvement. It must be noted, however, that as the present method is applied to an increasing number of projects to prevent or minimize disasters, new types of demand are beginning to appear, such as higher walls, those under more troublesome soil conditions and new structures to which the present method is inapplicable.

2. Necessity of Expanding Application

Measures to prevent or minimize disasters call for structures that can withstand huge earthquakes or tsunamis, work execution in coastal and mountainous regions as well as in urban areas, and greater vertical bearing capacity of walls. In consideration of the above, it is necessary to satisfy the following three requirements in relation to the construction of revetments of greater heights in hard soils in mountainous regions, which have increased in number.

(1) Increase applicable pile diameter

After the Great East Japan Earthquake in 2011, and in consideration of the Nankai Trough Earthquake, which is expected to strike the central and southern coasts of Japan in the next few decades, many large tide barriers are being planned and constructed along the Pacific coast of Japan. Such barriers must be designed to be highly resilient and tough against massive tsunamis. Conventionally, concrete and earth structures such as concrete blocks and concrete-covered dikes have mainly been used for such structures. However, when a massive tsunami is considered, such structures have to be large and often inviable at limited sites, and sometimes there is the risk of their crumbling and being swept away. On the other hand, driving rows of high-resilience steel pipe piles into soil for foundations enables the building of resistant and effective tide barriers at restricted locations. However, the drivable maximum pile diameter to date is 1 500 mm and the wall strength and rigidity would be insufficient in the event of a massive tsunami. Thus, larger pile diameters are required.

(2) Pile driving into hard soils and underground concrete structures

In the cases of urban rivers, foundations for revetments are constructed often in soft soils. Even if there are underground obstacles such as hard soils or buried concrete structures, they are near the ground surface in most cases. Therefore this method can install steel pipe piles by providing cutting bits at pile tips. In contrast, in the cases of tide barriers near coastlines, the soil is often hard in the total piling depth, or otherwise, there are rubble mounds not easily and economically removable beforehand and it is necessary to drive piles through them. In consideration of such cases, it is essential to establish a piling process capable of driving piles through such obstacles encountered either separately or in combination with each other.

(3) Application to bearing piles

The measurements of reinforcement for foundations of existing structures, which were abandoned because there are no economical and reliable work methods, are required. One solution to this is the installation of an additional pipe and SPSP. Such reinforcement, however, would mostly be performed at narrow sites, sometimes under limited overhead clearances, where conventional three-point-support piling machines are not usable. The Gyropress method was effectively usable under these conditions, but it lacked the procedure to confirm the bearing capacity of a pile being driven. Then, quality control regarding bearing capacity during the piling work to obtain a certain bearing capacity value, which was not required for a wall construction, is essential for anti-seismic reinforcement. Thus, it became necessary to incorporate these functions in the Gyropress method.

3. Activities for Larger-Pile Diameter Piles

3.1 Development of new driving machine

The applicable pile diameter of the Gyropress method was a maximum 1 500 mm. In order to drive piles of larger diameters, it was naturally necessary to design a larger driving machine. A larger machine, however, was likely to lose the advantages of the method, that is, the abilities of working in restricted areas and self-propelled movement. On the other hand, it is pointless if the method is not applicable to the assumed heights of tide barriers. Thus, we conducted a trial design of a self-standing wall 10 m in height to withstand a tsunami of a widely assumed magnitude, and defined the necessary pile diameter to be 2 500 mm. **Figure 7** shows the appearance of the pile driving machine designed to drive pipe piles of the size and specifications shown in **Table 1**.

3.2 Test construction using full-scale piles

To verify the operation and performance of the new type Gyro Piler and to confirm its capability of driving plies 2 500 mm in diameter, a piling test was conducted as illustrated in **Fig. 8**. The soil condition was as follows: from GL to a depth of 10 m, a gravel stratum having an N value of 10 to 30; and below it, a mixture of gravel and clay having an N value of 40 to 50. The reaction piles for the test were driven to a depth of 8 m below GL, and the test pile to 16.5 m.

The principal test items were (i) the actual rotational force and

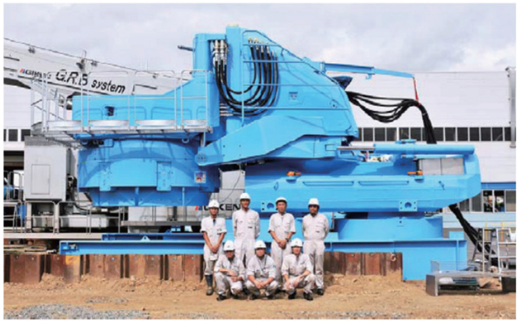


Fig. 7 Gyro Piler for 2 500 mm diameter pipe piles

Table 1 Machine specifications

Item	Specification
Pile diameter	2 000–2 500 mm
Maximum force	4 000 kN
Maximum torque	2 940 kNm
Weight	110 ton

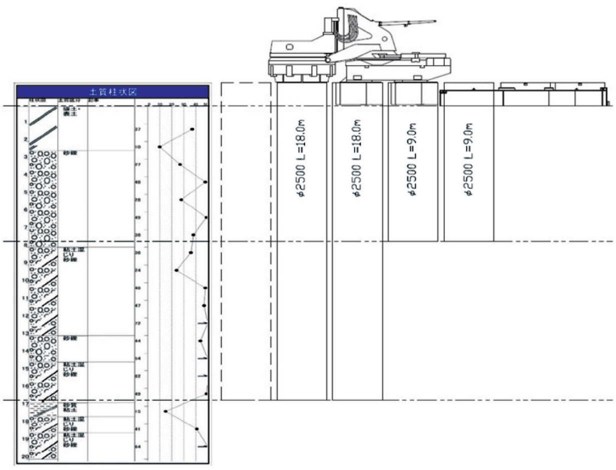


Fig. 8 Ground condition of piling test

Fig. 9 Test scenes

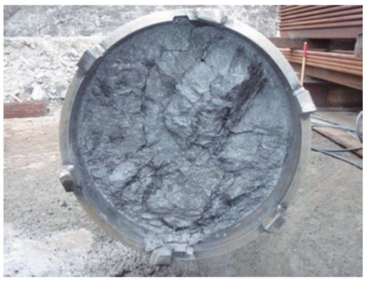


Fig. 10 Pipe pile clogged with hard soil

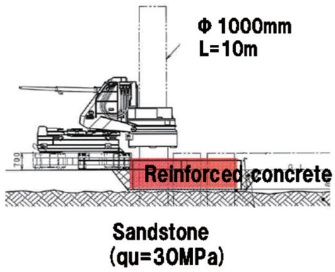


Fig. 11 Test of one-step pile driving

the downward pressure considered necessary for driving 2 500 mm in diameter piles, (ii) the self-movement of the pile driver, (iii) the piling operation at a corner, where a new pile is driven at a position at right angles to the center line of the driving machine, (iv) work monitoring and control procedures, and (v) the plier tongs designed for pressing in piles to a prescribed depth. **Figure 9** shows the test situations. During the test, power output substantially equal to the rated one was confirmed, there were no mechanical problems in turning the driving head at right angles at a corner, the work monitoring system and the plier tongs worked as intended, and the machine proved capable of driving the piles to the prescribed depth. The ability to drive 2 500 mm in diameter piles and a standard work method were thus confirmed, and the equipment was ready for actual construction.

4. Measures to Drive Piles through Hard Soils and Concrete Structures in Single Driving Operation

4.1 Issues in single-process operation

To drive a pile through hard soils or concrete structures buried comparatively close to the ground surface by the Gyropress method, conventionally, the piling work was divided into two steps: First, a hole is drilled through the hard layer by screwing down a drilling pile with special bits at the tip; Second, after pulling out the drilling pile, a permanent pile with ordinary cutting bits is screwed down to the originally designed depth. This is because the special cutting bits are expensive and have to be used many times to reduce costs, and additionally, the inside of the drilling pile is filled with hard soil material during the drilling through the problem layer, lowering the driving speed significantly or even making further driving impossible. In consideration of the cases where the soil is unstable and the earth falls into the hole after extracting the drilling pile or there is yet another hard layer below the one already drilled through, it is necessary to drive piles to an originally envisaged depth in one-step driving of permanent piles with ordinary cutting bits.

To this end, it was essential to improve the efficiency of rotation driving of permanent piles and eliminate factors that lower work efficiency. The principal reason for low work efficiency is that concrete lumps and rock are caught inside the pile and clog it because fines arise during their cutting and get between the material and the pile wall to increase the frictional resistance, and the hard material caught in the pile stays there even when the pile is driven further down (see **Fig. 10**). The increase in the driving load due to the pile clogging is more significant with hard rock or concrete than with sand or clay, and the water supply at the driving end has only a limited effect to improve the situation.

4.2 Improvement in driving operation

To increase the piling speed using ordinary bits, the number of the bits was increased, the downward pressing rate reduced and the rotation increased. On the other hand, the arrangement of the bits was changed to increase the excavation area on the inside of the pile wall so that a circumferential gap was secured there to prevent the clogging with hard materials., The injected water flowed under less restriction, and the cut fine was prevented from remaining close to the pile inside wall and moved with the water.

A test was conducted to evaluate the effects of the above measures. As shown in **Fig. 11**, a slab of reinforced concrete about 2 m thick was placed at GL +0.5 m to GL −1.5 m on alternate layers of sandstone and mudstone having a uniaxial compressive strength of approximately 30 MPa, and piles were driven by the Gyropress method. To simulate common base slabs for concrete revetments, the concrete slab was made by casting concrete, 20 MPa in strength, and arranging reinforcing bars of D16 to D22 on tiers of 250 × 250 mm grids. The test verified that it was possible to drive steel pipe piles through such concrete structure and soils in a one-step rotating and pressing operation with piles having an adequate number of cutting bits arranged appropriately at the lower tip.

4.3 Actual application

The upgraded Gyropress method was actually applied to real reconstruction of a coastal road revetment.[6] The foundation of the wall had been washed away and upended by high waves of typhoons, etc., the wall concrete had crumbled partially owing to material degradation, considerable amounts of the back-fill earth had been lost due to sagging of the road, and thus reconstruction was necessary. There were, however, certain conditions for the reconstruction work: (i) the road was very busy and the traffic was not to be restricted during the dismantling and removal of the old wall as well as during the construction of the new one; (ii) in consideration of endangered species and other wildlife at the sea shore adjacent to

(a) Scenes of wall construction

(b) Completion state

Fig. 12 Actual wall construction by Gyropress method

the road and the neighboring areas, their habitats were not to be disturbed; (iii) the site forms part of a touristic zone, and the noise and vibration during the work were to be kept to the minimum possible for the benefit of tourists and local residents. Moreover, the soil below the existing wall was mudstone having a uniaxial compressive strength roughly of 20 MPa and it was impossible to remove the old wall for fear of further sagging of the road.

The Gyropress method was suitable for this reconstruction work because of only mild effects on the surrounding environments and the ability to work within restricted areas, but with the two-step method, there was a possibility of the hole becoming unstable after pulling out the drilling pile. Therefore, a new development method to drive piles through hard soils in one work step was applied to this project. **Figure 12** shows scenes of the reconstruction work and the appearance of the renewed wall after completion. In the narrow work space only 2 m away from a busy road, steel pipe piles were driven through the existing wall by rotation piling and the work was completed without causing any hindrance to the traffic and the surrounding environment.

5. Application of Gyropress Method to Driving of Bearing Piles

5.1 Issues with bearing pile application

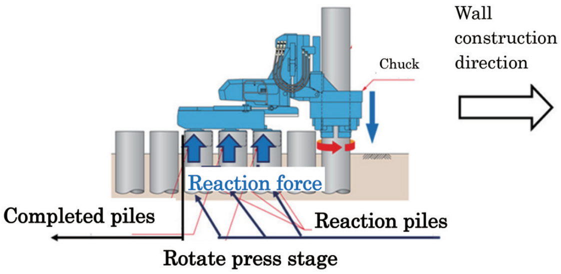
The bearing capacity of a steel pipe pile is evaluated in terms of the sum of the skin friction of the outer perimeter of piles and the end bearing capacity, but it depends on the driving method. The bearing capacity of a pile driven by the Gyropress method, however, had not yet been evaluated. For this reason, the value of the skin friction of an inner excavated pile was applied to the Gyropress method, similar to the driving method of rotation drilling. However, the end bearing capacity was not taken into account as far as the piles by the present method are concerned because there was no piling method for penetrating the bearing layer by rotating and press-in force. In that sense, the application of the Gyropress method to bearing piles was limited to the foundations of small bridges that inflict light loads on the piles.

Nevertheless, if a pile is driven by the Gyropress method to reach a firm bearing stratum, its end bearing capacity can be taken in account effectively in addition to the skin friction. For this purpose, it was necessary to establish work monitoring and control procedures, which confirm that a pile tip reaches a bearing stratum, and stop piling after confirming that the pile is firmly embedded there, and establish a method for verifying the bearing capacity based on the work monitoring and control procedure. The end bearing capacity of a steel pipe pile by the present method and its calculation method were submitted for study by relevant groups of specialists, and the bearing capacity figures have been included in the Design and Work Guideline of the International Press-in Association.[7] At present, however, they are regarded as reference information because of the small number of loading tests. The work monitoring and control procedures and the method for defining the bearing capacity are outlined in the following sub-sections.

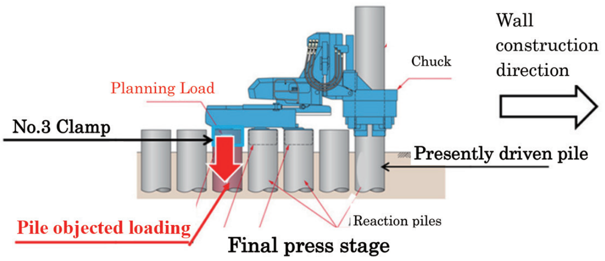
5.2 Work monitoring and control procedures

In order to identify that a pile has reached a bearing stratum, the correlation between soil boring log and change of press-in and torque force that can be monitored during the operation of driving was investigated. Regarding the embedding depth of the pile tip into the bearing stratum, the standard procedure to determine the bearing capacity of a pile by loading test is, as described in 5.3 below, to measure it after embedding the pile tip into the bearing stratum by a depth larger than the pile diameter. In consideration of this, the embedding depth was set, at present, equal to or larger than the pile diameter, excluding the cutting bits. The driving end is decided by statically applying a prescribed load, to be set in consideration of the soil condition and the machine capacity, to the pile immediately before the machine moves to the position of the following pile (see **Fig. 13**).

By the present piling method, the water injection is stopped when the pile being driven has reached the bearing stratum, and then it is turned and driven further for embedding by a depth equal to or greater than its diameter without the water supply. The piles on which the pile driver sits, which were driven before in the same manner, are used as the reaction piles for driving the current one, and therefore, upward force is applied to them. In consideration of this, the work monitoring and control procedures make it possible to firmly anchor the hind-most of the three reaction piles into the bear-



(a) Rotate press stage



(b) Final press stage

Fig. 13 End-of-driving procedures

ing stratum and confirm its bearing capacity after this. The pile driver advances to a new position thereafter leaving behind piles that have been confirmed to have the bearing capacity sufficient for the design load through the driving end control. The static load is applied, for example, by providing a jack in the No. 3 clamp, as seen in Fig. 13.

5.3 Verification of bearing capacity

To verify the bearing capacity of steel pipe piles driven through the above-mentioned driving end procedures, loading tests were conducted at three locations in Japan: Kansai (the region around Osaka, Kyoto, Kobe, etc.), Shikoku Island and Kanto (the region around Tokyo, Yokohama, etc.). **Table 2** shows the conditions and the results of the test.

The ultimate bearing capacity is defined as the loads at the pile top and the pile tip when the pile top dislocation is 10% of the pile diameter, and the N value at the pile tip is the soil hardness at the pile tip. **Figure 14** shows the relationship between the degree of bearing capacity and the N value at the pile tip under the condition of the ultimate bearing capacity, and **Fig. 15** the same between the maximum skin friction degree and the average N value of soil layers. The slanted solid line in Fig. 14 represents the gradient (60 N) of the bearing capacity degree relative to the N value at the tip of an impact-driven pile according to the Specifications for Highway Bridges [8] and assuming that the embedding depth is equal to the pile diameter, the horizontal solid line of the upper limit of the bearing capacity degree is defined by the N value, and the slanted dotted line is of the same gradient assuming that the pile tip bearing capacity degree increases endlessly and linearly in relation to the N value. On the other hand, the slanted solid line in Fig. 15 shows the relationship between the skin friction degree of an inner excavation pile according to the Specifications for Highway Bridges and N value, and the horizontal solid line of the upper limit value of the skin friction degree.

The values of the bearing capacity degree of the test piles driven by the developed method far exceeded the design value in consideration of the upper limit shown with the solid lines. Their values of the skin friction degree were equal to or better than those of the inner excavation piles used currently for foundation design. The present piling method is now expected to fully exploit its capability to verify the bearing capacity of every pile through the established work monitoring and control procedures, and further, to accumulate more loading test data to firmly establish the credibility of the pile tip bearing capacity.

Table 2 Results of vertical loading test

Site area	Diameter of pile (mm)	Length of pile (m)	Soil property of bearing layer	N value at pile end	Ultimate bearing capacity (kN)	
					Pile top	Pile end
Kansai	800	21.0	Gravel	64	4168	2548
Shikoku	800	18.0	Gravel	44	4060	2368
Kanto	1000	15.5	Sand	72	6363	3576

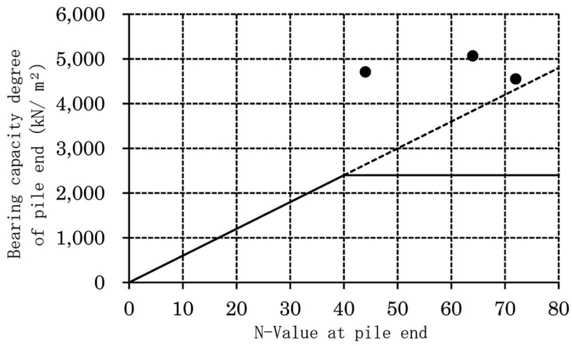


Fig. 14 Bearing capacity degree of pile end

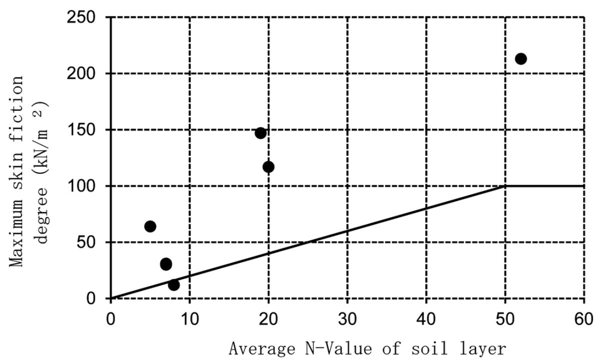


Fig. 15 Skin friction degree

6. Closing

The Gyropress method has wide applications to disaster prevention and infrastructure construction in urban areas, the need for which is expected to greatly increase. In order to fulfill the requirements in the construction field that the present method was unable to meet before, we have devised new technologies and incorporated them into the method as additional functions, which proved effective at expanding the applicability of the method. Although there has been only a small number of applications in which the newly added functions were fully exercised, field expertise will be accumulated through more practice, to reinforce the reliability of the method. In addition, we intend to further clarify the mechanism of the pile bearing capacity of the method, and strengthen its ability to respond to more varied market needs.

Acknowledgements

The Gyropress method is the product of joint development with Giken, who exerted great efforts in the initial studies, development of the piling machine and the field operation processes toward its establishment and market cultivation and expansion. We would like to express our profound thanks for the invaluable assistance of all affiliates of Giken.

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