Technical Report

# Case Studies of Steel Pipe Pile Methods Suitable for Variable Construction Conditions

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**Abstract**

***Since the high economic growth period when there was widespread application of steel pipe piles, steel pipe pile construction methods and members that meet new needs have been required. This paper shows the development of steel pipe pile construction methods and members and application examples in railway construction.***

## 1. Introduction

In the high economic growth period during which urban development and infrastructure construction rapidly advanced, plenty of infrastructure was developed in coastal areas where most ground was soft. There were new needs for large-scale structure construction and ensuring seismic resistance, and the number of cases in which wooden piles, which had been mainstream until then, could not be applied increased. Steel pipe piles could meet these multiple needs. Compared to wooden piles, steel pipe piles have greater flexural rigidity, lateral resistance, and bearing force, and they have the added advantage of being suitable for long-length construction. Accordingly, many steel pipe piles were adopted for foundation piles in a stroke by drawing on the characteristics. At that time, the pile-driving method was widely used due to its speed and cost-effectiveness. After that, awareness of the environment rose and the Japanese Noise Regulation Law (announced in 1968), etc. were enacted, which demanded for a transition to construction methods with low noise and less vibration. In addition, for construction work in urban areas, there were demands for construction methods that produce less excavation. To resolve these issues, Nippon Steel Corporation and other steelmakers cooperated with pile construction companies to develop the inner-excavation piling method (put into practical use around 1985, **Photo 1**).[1)]

In 1990 and after, in which urbanization advanced, there have been more needs for construction methods that minimize excavation and have a larger bearing force than that of the inner-excavation piling method, due to the increase in design loads and other reasons. Moreover, as the applicable scope of steel pipe piles has been expanding, for example, high-strength steel pipe piles, construction in narrow sites, and construction on hard ground, there have been demands for steel pipe pile methods and materials that satisfy new needs.

**Photo 1 Inner-excavation steel piling**

This paper introduces steel pipe products that we have developed so far and steel pipe pile construction methods in which their characteristics are effectively utilized as well as cases where our steel pipe piles were applied to railway construction by drawing the best out of their characteristics.

## 2. Steel Pipe Pile Construction Methods that Satisfy Various Needs and Case Studies

### 2.1 Gantetsu pile™ with high bearing force that enable less excavation

#### 2.1.1 Characteristics of Gantetsu pile™

The cost of a foundation can be reduced by increasing the bearing force per pile, reducing the number of piles, and, as a result of such number reduction, downsizing the footing. To satisfy such requirements, Nippon Steel and Tenox Corporation, etc. cooperated to

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develop Gantetsu pile™ shown in **Fig. 1**.[2] Gantetsu pile™ are synthetic piles consisting of soil cement columns and steel pipes with outer ribs; soil cement columns are constructed by stirring and mixing the ground larger than the outer diameter of steel pipes by 200 to 400 mm and mixing cement. The soil cement, which has a specific gravity almost the same as that of the in-situ ground, constantly acts as hydraulic pressure on the hole walls. Therefore, there is no loosening of the ground during construction, and it is characterized by stable bearing performance in terms of both tip bearing force and shaft friction force. Accordingly, the stress around the piles is not released, resulting in a particularly larger shaft frictional force compared to other pile construction methods. Moreover, because the bearing force can be evaluated based on the soil cement pile diameter, Gantetsu pile™ are effective for securing the bearing force on soft ground. Accordingly, they are highly applicable as intermediate support piles and frictional piles. In addition, because the ground at actual sites is used to establish soil cement columns, the volume of earth to be discharged can be reduced compared to the inner-excavation piling method.

#### 2.1.2 Case study of Gantetsu pile™ as intermediate support piles by taking full advantage of their high frictional force

This section introduces Hokuriku Shinkansen extension work, in which Gantetsu pile™ were applied as intermediate support piles friction piles that disregard the end bearing capacity from a design perspective for the first time in high-speed railways because their high frictional force was highly valued.

The area south of Fukui Station, known as Shimokogita, is characterized by a wide spread of soft ground. The distinct support layers are 90 m or more deep at the deepest locations and thereby applying completely supported piles was difficult in the area. Completely supported piles are used as a standard method for foundation piles for elevated railway bridges. However, due to the ground conditions of the extension work, intermediate support piles that would be driven to the diluvial layer and stopped there were considered. The cast-in-place pile construction method is adopted for many foundation piles in various sectors, in addition to the railway sector. However, it was found that the foundation structure could not be established by relying solely on the shaft frictional force in the cast-in-place pile construction method. The Gantetsu pile™, known for its superior load-bearing performance, was brought into focus. When the frictional force values of the two construction methods are compared according to the Design Standards for Railway Structures and Commentary[3], the coefficient of Gantetsu pile™ is approximately 1.7 times larger and the upper limit of Gantetsu pile™ is approximately 1.3 times larger. By drawing on this high frictional force, it was possible to achieve an economical design by reducing the pile diameter and length. Thus, Gantetsu pile™ were used as intermediate support piles (steel pipe diameter of 1 300 mm, soil diameter of 1 500 mm, and pile length of approximately 50 m) for the first time in high-speed railways.

### 2.2 NS ECO-PILE™ with high bearing force that enables no earth discharge construction

#### 2.2.1 Characteristics of NS ECO-PILE™

Earth to be discharged during pile construction is regarded as industrial waste and thereby there are great needs for no earth discharge construction. Such needs become greater in construction work on ground containing nature-derived heavy metals and sites where factories previously stood, in particular. We developed NS ECO-PILE™ shown in **Fig. 2** to enable no earth discharge construction while large bearing force is secured.[4] NS ECO-PILE™ is a steel pipe pile with a helical blade welded at the steel pipe end. The construction method is a rotary piling method in which a full slewing machine or other similar equipment is used to rotate the steel pipe to press fit the pile. The wedge effect of the blade works to push the earth upward and the reaction force is used as the driving force to push in the pile underground. The blade's expansion effect exerts large push-in bearing force and pull-out resistance at the pile end. Excavated earth and sand are taken into the pipe from the open end at the blade end, which enables no earth discharge construction. This environment-friendly pile construction method with low noise and less vibration can also be used for construction work in cities and construction close to existing structures. Moreover, batter piles can be constructed by the angle setting of a pile driver. This steel pipe pile construction method can satisfy various needs: The batter pile structure can enhance the lateral resistance without increasing the number of piles; and the helical blade at the pile end works as a

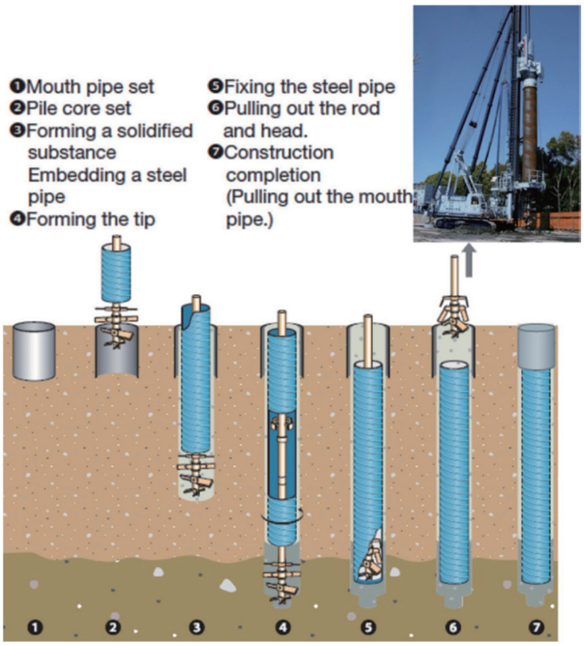


**Fig. 1 Gantetsu pile™**

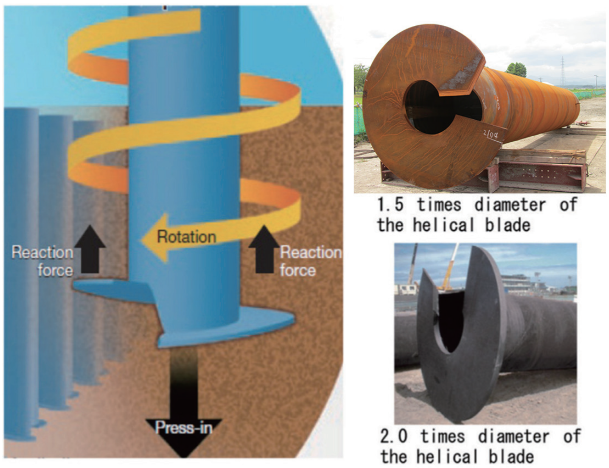


**Fig. 2 NS ECO-PILE™**

screw and thereby the pile can be pulled out by reversing the rotation direction from the direction in which the pile is pushed.

### 2.2.2 Case study of NS ECO-PILE™ with excellent lateral resistance as batter piles

To suppress lateral displacement of rigid-frame elevated bridges on the Hokuriku Shinkansen railways, NS ECO-PILE™ was adopted focusing on the batter pile structure, which is a characteristic of NS ECO-PILE™.

The ground of Kibagata in Komatsu and the surrounding area is extremely soft, making it a challenge to suppress lateral displacement of rigid-frame elevated bridges during earthquakes. To control displacement within the allowable range using straight piles, which are generally used as foundation piles, it would be necessary to increase the pile diameter, plate thickness, and the number of piles. However, due to a constraint of the construction site, it was difficult to increase the foundation size and thereby simply increasing the pile diameter and the number of piles would not be an option. Batter pile structure using NS ECO-PILE™ resolved this issue. For straight piles, the lateral resistance of the pile foundation is flexural rigidity only. On the other hand, for batter piles, the shaft rigidity resistance by the oblique angle of the shaft can be effectively used. Accordingly, when the pile diameter is the same, the foundation's lateral rigidity can be higher in the case of batter piles. Also considering the results of research on batter pile foundations by the Railway Technical Research Institute in Japan, et al.,[5, 6] batter pile structure using NS ECO-PILE™ was applied (steel pipe diameter of 1 200 to 1 500 mm, pile length of approximately 40 m, **Photo 2**) for the first time to railway construction.

## 2.3 Enabling construction on both narrow sites and hard ground

### 2.3.1 Characteristics of Gyropress Method™

The press-fit construction method (put into practical use around 1990) is a steel pipe piling method that works well for narrow site construction. This method, which produces low noise and vibration, uses the already installed multiple steel pipe piles in the ground as a reaction force to press in the next steel pipe pile using static load. In addition, a construction machine moves along the top of the steel pipe piles, eliminating the need for a separate work platform. Therefore, construction on narrow sites where large construction yards cannot be secured is possible. However, the press-in method, which uses static loads to push in the piles, has been less effective on hard ground compared to other steel pipe pile methods. To resolve the issue, Nippon Steel and Giken Ltd. cooperated to develop the Gyropress Method™ shown in **Fig. 3**.[7] In this construction method, a Gyro Piler™ is used to rotate and press-fit a steel pipe pile for which a ring bit has been installed at the steel pipe end. This method can directly penetrate even existing concrete structures, to say nothing of hard ground (e.g., bedrock).

### 2.3.2 Case study of Gyropress Method™ as a measure against landslides

As described previously, the Gyropress Method™ can be applied to construction under hard conditions, such as narrow sites and hard ground. This section introduces a case of application as a measure against landslides by drawing on the characteristics.

For Sonogi river bridge construction work (bridge length of 370 m) for the Kyushu Shinkansen, the entire construction site was located in a landslide prevention area. Accordingly, in addition to the main bridge body construction, a measure against landslides was required.[8] Landslide prevention construction methods are divided into prevention work and control work. This time, to directly protect the bridge over which the Kyushu Shinkansen, which is a public transportation system, would run, prevention work was selected as a measure against landslides; for preventive work, the resistance of the structure is used to stop all or part of the landslide movement.

The construction conditions were very severe; The construction site's ground was a bedrock layer (classes CL and CM) and the preventive pile construction location was on a slope. Generally, to construct preventive piles on hard ground, a large-diameter boring machine is used to dig the ground in advance and steel pipes whose pile diameter is approximately 500 mm or smaller are buried in many cases. This time, this construction method was also considered at first. However, there was an issue that pile construction alone would take a long time because piles would have to be embedded deep into the bedrock layer (classes CL and CM) and the target area requiring the measure was wide. In addition, to construct preventive piles on a slope, a temporary pier is required and thereby the period to construct a pier and its cost also needed to be taken into account.

These issues were resolved by the Gyropress Method™ that enables construction on both narrow sites and hard ground. To reduce the construction period and cost, the number of piles was reduced

Photo 2 Batter-piling

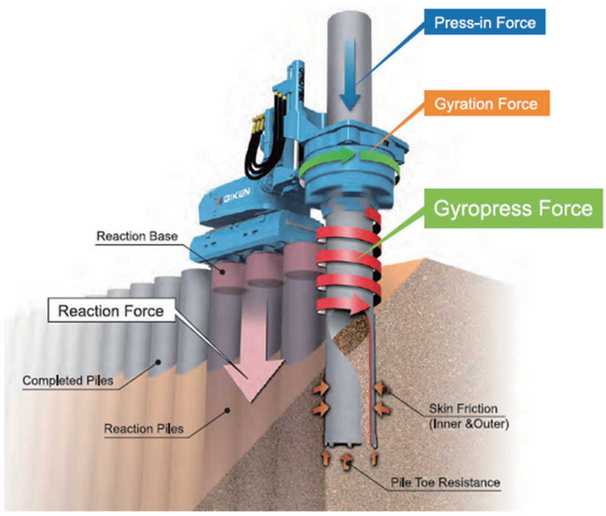


Fig. 3 Gyropress Method™

Photo 3   Skiplock Method™

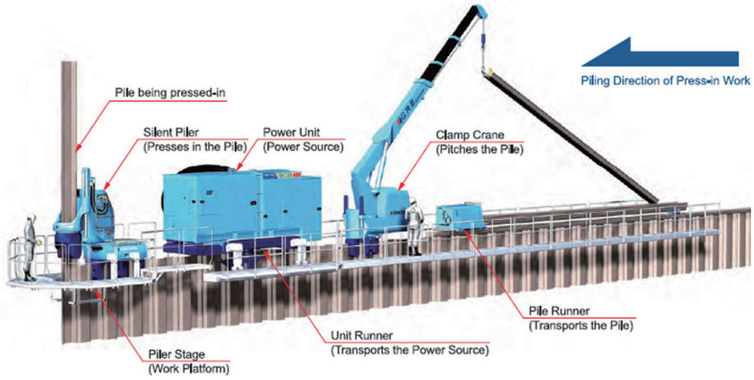


Fig. 4   Non-Staging Method

by using larger-diameter piles and 1200-mm-long steel pipes were placed at intervals of 3.0 m. Although the intervals between piles cannot be large in the regular Gyropress Method™, combining the Gyropress Method™ with the Skiplock Method™ (**Photo 3**) enabled constructing piles at large intervals. Moreover, to eliminate temporary construction, the Non-Staging Method (**Fig. 4**) was adopted. The Non-Staging Method refers to a system in which the pile heads are used as a work track to transport a piler, power unit (hydraulic power source), Clamp Crane™ to build piles, and Pile Runner™, which is used to transport piles from the operation base, etc. This method eliminated the need for temporary work of temporary piers, and temporary roads, etc., making the construction work effective.

## 3. Enhancement of Application Flexibility by Making the Most of Manufacturing Technologies and a Case Study

### 3.1 Steel pipes with on-bead shear keys

Because there is restriction on the pile diameter due to the increase in the design loads and foundation size limitation, there are more needs for pile bodies with high yield strength. One possible measure to enhance the pile yield strength is combining piles with concrete to form synthetic structure. For example, steel pipes with inner ribs are used at the heads of cast-in-place steel pipe concrete piles. Steel pipes with inner ribs are manufactured as follows: Ribs are formed on steel plates by hot rolling in the hot-rolled coil manufacturing process and such plates with ribs are used to form pipes such that the ribs come inside the steel pipes. Meanwhile, steel pipes with outer ribs are formed such that the ribs come outside the pipes and such pipes are used for Gantetsu pile™, etc. These hot-rolled steel pipes with ribs are suitable for mass production because their manufacturing efficiency is high. However, if a steel pipe for which the thickness varies is required in volume, the production may be inefficient. There are also restrictions on the rib height, plate thickness, and material strength that can be hot rolled.

To improve the manufacturing efficiency and eliminate the manufacturing restrictions, we developed steel pipes with on-bead shear keys. Steel pipes with on-bead shear keys are manufactured as follows: Regular steel pipes are manufactured and on-bead shear keys (**Photo 4**) that were formed into the designated shape while a welding material was being melted are mounted. There are three types of pipes with the on-bead shear key height of 6, 8, or 13 mm and the appropriate one is used depending on the application purpose and structure to be applied. The on-bead shear key manufacturing technology enabled small lot production and mounting shear keys in any

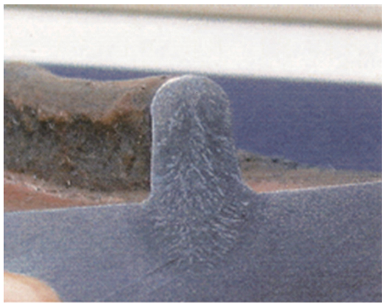

Photo 4   On-bead shear key

location without restrictions on the plate thickness and material quality. Currently, appropriate types are rationally selected from hot-rolled steel pipes with ribs and steel pipes with on-bead shear keys depending on customer needs, such as the number of shear keys/ribs, range with keys/ribs, steel pipe plate thickness, and material quality. The adhesion performance of on-bead shear keys was evaluated as equal to that of flat bars and steel bars by the Public Works Research Center in Japan[9] and as equal to that of hot-rolled outer ribs by the Railway Technical Research Institute in Japan.[10]

### 3.2 Cases study of steel pipes with on-bead shear keys as Gantetsu pile™

This section describes a case study of elevation of the Matsuyama station and JR Yosan Line. In this case, steel pipes with on-bead shear keys were effectively utilized to achieve construction of Gantetsu pile™ that are thicker than conventional steel pipes with outer ribs.

The urban area around JR Matsuyama station is divided into eastern and western parts by the JR Yosan Line that extends north and south and a railway yard/freight station and thereby, traffic jams due to closed crossing gates are observed daily. To resolve traffic jams and eliminate risks of crossing accidents, a project to elevate the railway tracks for approximately 2.4 km was started.[11]

There were restrictions on the construction site and elevated bridge foundation size due to the site. Under such circumstances, steel pipe soil cement piles were adopted as the pile foundation from the perspective of reducing pile diameter by utilizing their high bearing force. To secure appropriate intervals between the piles, the considered upper limit of the steel pipe diameter was 1300 mm based on past records and as a result, the required thickness was 25 mm at maximum. However, the maximum thickness of steel pipes with outer ribs manufactured by Nippon Steel for which the diame-

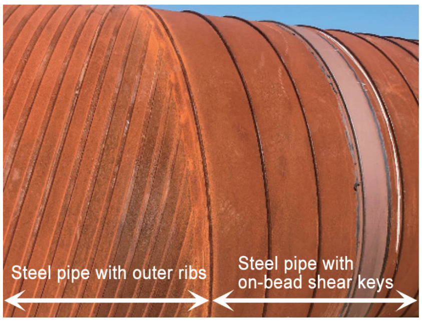


**Photo 5 Combination of the roll-formed and on-bead shear keys on pile surface**

ter was 1300 mm was 22 mm, which posed the issue that regular steel pipe production would not work. To resolve the issue, we focused on the on-bead shear key production technology: On-bead shear keys were attached to the outer surfaces of spiral steel pipes for which the pipe diameter was 1300 mm and the plate thickness was 25 mm to form steel pipes with outer ribs. As a result, to form a single steel pipe pile, two types of steel pipes manufactured by different methods were combined as the pile structure. The section with the plate thickness of 22 mm was a steel pipe with outer ribs and the section with the thickness of 23 mm or larger was a steel pipe with on-bead shear keys (**Photo 5**).

## 4. Conclusion

This paper introduced case studies of construction in the railway sector where the construction methods' characteristics were fully utilized. As described in the cases, application of Gantetsu pile™ as frictional piles, application of NS ECO-PILE™ as batter piles, and combined use of the Gyropress Method™ and Skiplock Method™ were outcomes of development that we conducted to improve the technical levels beyond the conventional technologies. We also added steel pipes with outer ribs and steel pipes with on-bead shear keys to our product lineup. It can be said that the development of both of these products and construction methods have been resolving issues at actual work sites.

Moreover, based on the results of the application to the railway sector, application of our products has been expanding to the road sector and other sectors. Examples are the application of NS ECO-PILE™ as batter piles for ramp bridges on the Tokai-Kanjo Expressway, application of Gantetsu pile™ as frictional piles for the foundation of a drainage pump station to be constructed on soft ground, application of on-bead shear keys to the shear connectors at the ends of Gantetsu pile™, and application of the Gyropress Method™ to reinforce small earth dams at narrow sites on hard ground. We will continue to contribute to resolving various issues in the construction sector also in the future by developing steel pipe pile construction methods and products that satisfy social needs.

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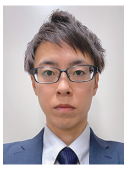

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