# Rock Press-fitting Excavation Record by Pipe Drilling Method

Terumichi HATA
*Mechanical Engineering Center, Kajima Corporation, Tokyo, Japan*
*Email: hata@kajima.com*
Masaaki KASAKAWA
*Hokuriku Branch, Kajima Corporation, Niigata, Japan*
*Email: kasakawa@kajima.com*
Keisuke OHTSU
*Hokuriku Branch, Kajima Corporation, Niigata, Japan*
*Email: ohtsu@kajima.com*

**ABSTRACT**

In the earlier method of excavating a rock with rotary all casing boring machine, it was common to disintegrate the rock mass by freely dropping heavy weight (chisel etc.) inside the casing. However, in that method (dropping chisel), the foundation rock was getting damaged and whenever it was necessary to provide a water proof wall to the rock bed layer, this was a disadvantage. At the same time when crushing with chisel, there was a problem that the drilling efficiency used to drop significantly in the case of a large depth and under water excavation. In order to solve these problems, an excavation was carried out by a pipe drilling method (our developed technology) that reliably transmitted rotational torque from a rotary all casing boring machine and excavated without cracking the rock, this has yielded good results and hence we are reporting the summary and results.

***Key words:*** *Rotary press fitting, Rock drilling*

## 1. Pipe drilling method

### 1.1. Outline of construction method

The pipe drilling method is a construction method in which the torque of the rotary all casing boring machine is transmitted to the pipe drill by a link mechanism which does not require hydraulic pressure to cut the hard ground. Compared to the conventional method of crushing, this method can control the drilling efficiency in water and deep excavation. This method allows the rock excavation with low noise and low vibration without damaging the foundation rock. The excavation diameter corresponds to φ 1,000 mm to φ 3,000 mm.

### 1.2. Points for developing construction method

In the conventional digging device, a hydraulic mechanism such as a hydraulic cylinder was applied to transmit the rotational torque of the casing to the bucket. For this reason, the hydraulic control device suffers large scaling and the workability drops due to the handling of the hydraulic hose.

The remarkable point of this method is the

**Photo 1.** Overview of Pipe drill

restore-protrude mechanism of the pins; the pins that are attached on the drill synchronously are restored when the drill is hung and protrude when the drill reach the bottom and set on the ground, corresponding to the movement of the stabilizer (**Fig 1**). After the drill reaching the bottom, the pins are hung to the corner of the "reaction windows" (**Fig 2**), a dent placed inside the casing, corresponding to the rotational movement of the boring machine. By hanging pins to the "reaction windows", the torque of the boring machine can be transmitted to the pipe drill. It is a simple mechanism that realizes attachment and detachment of the first casing and the pipe drill by the pin.

Since this transmission mechanism does not depend on the frictional resistance by grip, which may cause slippage of the casing, it is possible to transmit the rotational torque of the casing to the pipe drill in better reliability.

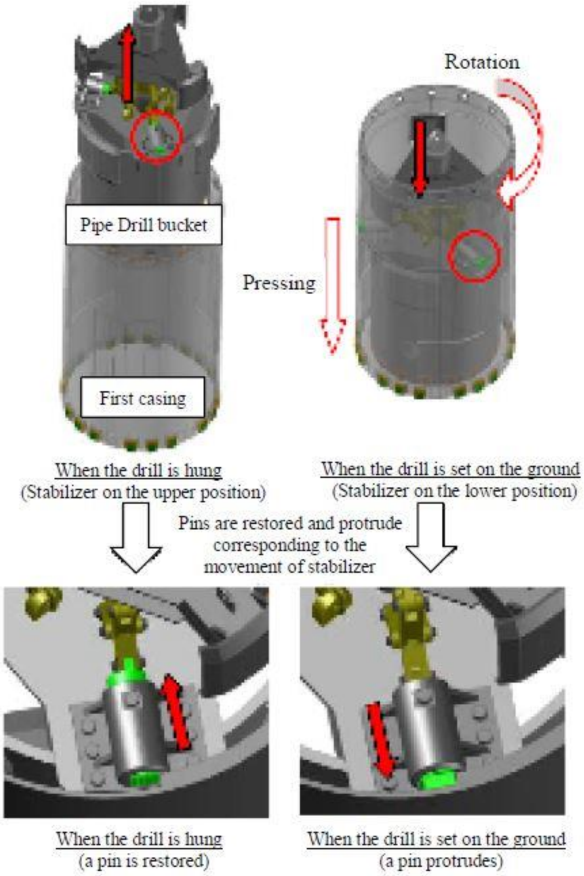



**Fig. 1** Overview of pipe drill mechanism

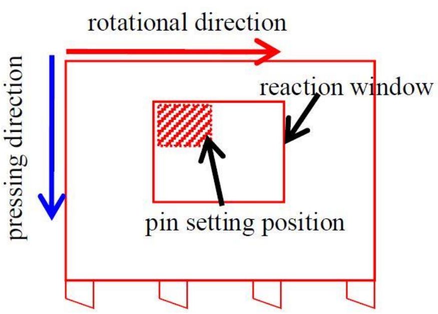



**Fig. 2** Inner view image of First Casing

### 1.3. Pipe drilling mechanism

The mechanism of Pipe drill is as follows. When the main body is inserted into the casing and reach the bottom, the hanging wire become loosened, the stabilizer descends and the pin protrudes (**Photo 2**).

After reaching the bottom, by rotating the casing, the pins are hung in the corner part (as shown in **Photo 3**) of the "reaction window". Thus, the torque force of the rotary all casing boring machine is transmitted to the pipe drill and dig the rock.


**Photo 2.** Pipe drill

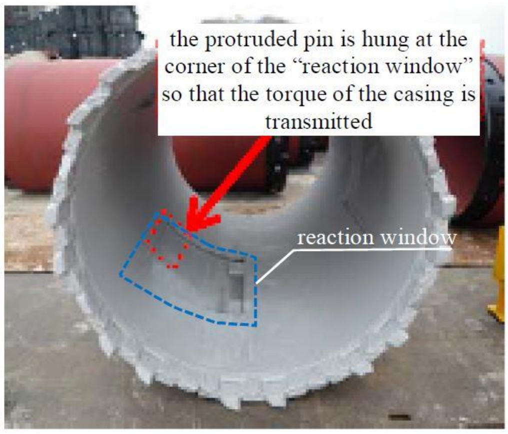



**Photo 3.** First Casing

After completion of excavation, by rotating the casing reversely and lifting the main body, the pins are restored, the main body is detached from the first casing, and it can be lifted up.

### 1.4. Excavation mechanism

A conical bit is applied as a bit of the cutting edge of the pipe drill. The conical bit is capable of cutting the rock surface uniformly by rotating the bit itself under the high pressure on the surface, which contributes to mitigating the abrasion of the bit. Basically, one conical bit is set on one trajectory, but it is also possible to set two bits on one trajectory according to rock strength (**Photo 4**). In addition, to facilitate bit exchange, three spokes are formed as a box structure, and the bit is attached and fixed by a snap ring (**Photo 5**). The casing bits are also attached to the outer surface of the casing. The image of settled pipe drill is shown in **Photo 6**.

## 2. Outline of construction

### 2.1. Structure form

The workability of such pipe drilling method was evaluated, and it was applied to actual construction.

This construction is to build a steel pipe sheet pile and a columnar wall as a water retaining wall as well as a soil retaining wall around the excavation area for foundation construction in the landfilled coastal areas in Japan.

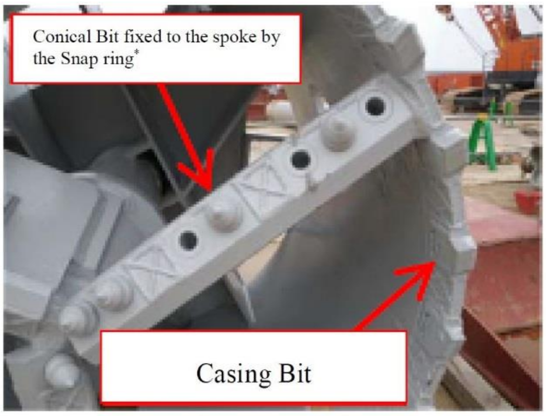
The steel pipe sheet piles are designed to be adopted to the deep excavation area. The columnar wall made of mud mortar and H-steel are designed to be adopted to the shallow area.

The steel pipe sheet piles are constructed by press-fitting and inner excavation in combination, preceded with replacing the soil by mud mortar. The columnar walls are constructed by replacing the soil by mud mortar and inserting H-steel. The all casing boring machine is applied for replacing excavation, and the pipe drill method is adopted for drilling the rock layer, which is possible to cut the rock without loosening the hard layer.

### 2.2. Geological conditions

The surface ground in this site consists of a landfill made of crushed rock with maximum diameter of 300mm. The stratigraphic composition under the landfill layer consists of alluvial sand layer (As layer), alluvial gravel layer (Ag layer), diluvial layer (Dg layer) and the layer of granite (Class D, Class CL or higher). As a special feature, the riprap layer of the caisson is sandwiched between the landfill layer and the alluvium deposit at the steel pipe sheet pile area, and at the area of

**Photo 4.** Drilling bit shape




*Snap ring is located on back of Conical Bit in the box structured spoke

**Photo 5.** Bit shape in large figure

**Photo 6.** Pipe drill setting status

columnar wall, rock layer lays just right under the landfill layer. The groundwater level fluctuates synchronously with the tide level.

### 2.3. Construction period

The construction started from 2010 and lasted until 2011.

## 3. Construction results

### 3.1. Construction procedure

The excavation was basically done by hammer grab, and the pipe drill was applied when reaching the hard rock layer, removing the crushed rock by hammer grab (**Fig. 3**). The construction procedure of the pipe drilling is shown below. The drilling length of one stroke is set to about 0.4 m.

① Pre-drilling by casing
② Pipe drill insertion, cutting, lifting
③ Earth removal by hammer grab

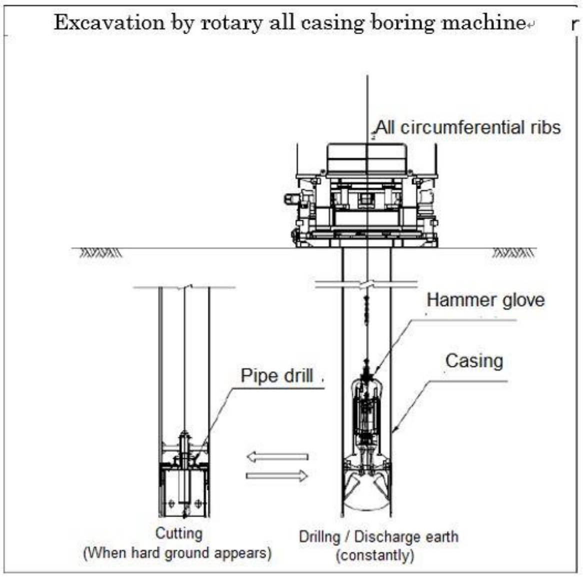



**Fig. 3** Excavation procedure

### 3.2. Record of the pipe drill excavation

Rotary press-fitting and cutting by the pipe drill made stable results regardless of hardness of the ground.

Since hard ground appears in the deeper portion of excavation, the construction cycle time is influenced by the abrasion extent of the casing bit for pre-drilling. For this reason, it is important to notice the timing for casing bit exchange.

**Table 1** and **Fig. 4** show an example of excavation results. The excavation diameter is φ1,500 mm, the depth of excavation is GL - 14.5 m, and the rock classification mainly consists of middle hard rocks of Class CL or higher.

In this site, the pipe drill was applied for hard rock of $q_u$ = 60 to 100 N / sq mm grade. The time for pipe drilling was about 30% of the total time for rock excavation on average, although it varied depending on the rock classification. The excavation time per 1 meter is 83.5 min on average, which is about 10% faster than the drilling efficiency of the conventional method of chisel drilling (reference: cumulative basis 92.8 min / m). The image of drilled wall and the bottom are shown in **Photos 7** and **8**.

### 3.3. Troubles during replacement excavation

Several troubles happened during replacement excavation such as shown below.

(1) Collapse of the surrounding ground

During the replacement excavation, the ground beneath the rotary all casing boring machine frequently collapsed into a mortar shape. It was assumed to be caused by the evacuation of landfilled soil into the clearance between the revetment caisson and ground. As a countermeasure, void filling and protection of cavity wall by mud mortar were carried out.

(2) Resumption of excavation

The excavation was stopped for several times due to the reasons such as abrasion of casing bit, blockage of

**Table 1.** Excavation record

| | |
|---|---|
| Drilling diameter | Dia 1500mm |
| Rock Classification | Class CL or higher |
| Rock drilling length (a) | 6.5m (GL-8.0~14.5m) |
| Rock drilling time (b) | 543min |
| Pipe drill (PC) use time (c) | 137min |
| PD usage count (d) | 9 times |
| Net drilling speed (b/a) | 83.5min/m |
| PD use ratio (c/d) | 25.30% |
| PD cycle (Insertion drilling - pulling up (c/d) | 15.2min/time |
| First bit consumption (casing) conical bit | 0.55pieces/m |
| Conical bit consumption (Pipe drill) | 0.11pieces/m |

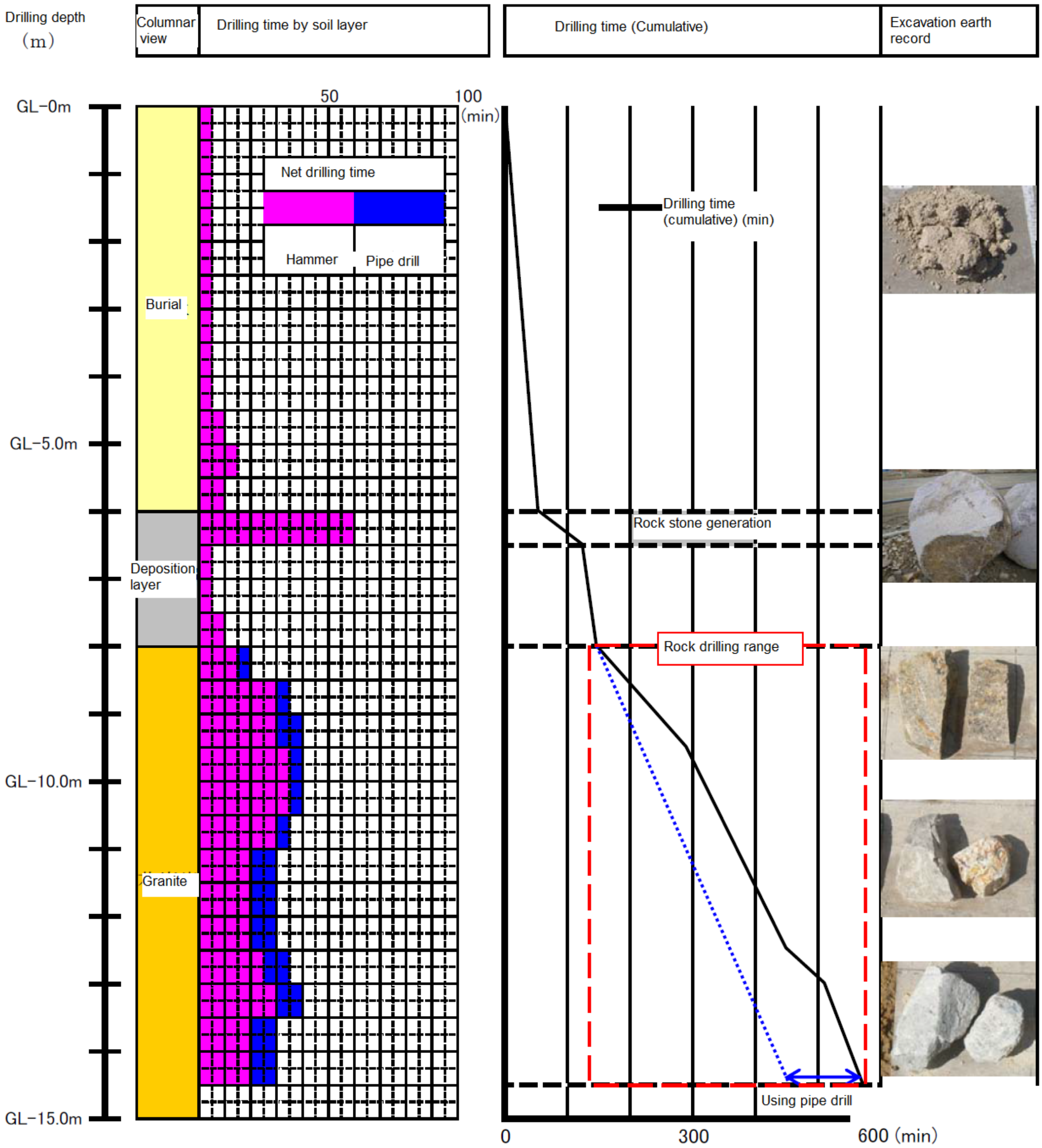



**Fig. 4** Drilling depth and drilling time

casing by big boulder and acute increase of torque force (**Photo 9**).

As a countermeasure, the casing was pulled out and re-drilling was carried out after filling back with original soil or mud mortar.

(3) Lock of casing

Casing was locked by jamming several times; by the impossibility of drilling due to excessive frictional resistance between the casing and the ground. As a countermeasure, supplemental drilling by a rotary percussion drill with diameter of 165mm, number of 18 was carried out around the casing in order to reduce the friction. Afterward, locked casing was resumed using the rotary all casing boring machine.

(4) Pipe drill blockage

There was a case that pulling up the pipe drill has been impossible. The reason was assumed to be excessive pushing of the pipe drill as much as 40cm

**Photo 7.** Drilled wall after excavation

**Photo 8.** Drilling bottom

**Photo 9.** Inner blockage of casing by boulder

deeper than the bottom of casing or blockage of the gap between casing and the pipe drill (about 7 cm) by crushed rock (**Photo 10**).

As a countermeasure, the top of the pipe drill in the casing was hit with a reverse rod to cut the friction between the pipe drill and the casing.

**Photo 10.** Adhering of crushed rock

### 3.4. Quality control

In order to ensure the function of water barrier, it is necessary to ensure the lap of the mud mortar in the embedment part. For this reason, the vertical accuracy of excavation is required to satisfy the regulation shown in **Table 2**.

As mentioned above, the geological condition in this construction was not a homogeneous stratum and riprap layer or presence of boulder were also expected. Therefore, taking the data obtained from the excavator such as rotation torque, current value etc., and the geological conditions into account, the thrust load and the rotation speed was controlled. In addition, the verticality of the casing was examined by transit from two directions. As a result, the vertical accuracy of drilling in this construction resulted in becoming less than 1/400 measured by ultrasonic measurement, which satisfied the requirement.

In this type of pile construction, grasping the

**Table 2.** Drilling vertical accuracy

| Drilling diameter (mm) | 2000 dia | 1500 dia |
|---|---|---|
| Construction interval (m) | 1.45 | 1.25, 1.20 |
| Max depth (m) | 42 | 32.5 |
| Drilling vertical | 1/200 or more | 1/300 or more |

position of the pile applying GNSS, etc. has already been addressed. However, it will be necessary for contractors in near future to collect all the data concerned with drilling such as excavation depth, ground type, embedment depth, drilling time and photos of excavated soil and to develop the integration system of those data including torque, current, pressing force, inclination and machine position, so called ICT construction so that the construction of qualified structure that satisfy the clients' demand will be possible without relying on the skilled workers.

## 4. Conclusion

According to this work, the pipe drilling method confirmed that excavation is possible even for hard rocks of $q_u$ = 60 to 100 N / sq mm. Moreover, the adequate performance was confirmed also in underwater rock drilling at the maximum depth of GL - 42 m.

Since this method is focused on not damaging the bearing rock, it is widely applicable to waterproof wall construction and water barrier wall construction with rock drilling.

Regarding the safety aspect, there was almost no shaking of the crane while using the pipe drill, so there was a sense of security compared to crushing by chisel.

From now on, this method can be widely deployed as one of the tools for rock drilling work with rotary all casing boring machine. The development of this method is continuing so that this method shall be developed over varieties of engineering field.