Application of Water Jet Cutting to Treatment for Obstructive Piles

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ABSTRACT

This paper presents an application of the water jet cutting method to a treatment for obstructive piles on a planned line of shield tunneling. An automated cutting system and a monitoring system, developed for this treatment, support the work of cutting PHC (Prestressed High-strength Concrete) pile into small pieces before the passage of a shield tunneling machine, and then, the shield machine can excavate and move forward safely. The existing building on the obstructive piles is kept in the original state by underpinning works in combination. On the practical application, the water jet cutting work and the shield tunneling work have satisfactorily done in a short period of time.

1. INTRODUCTION

Recently, pile foundations have hindered frequently in urban construction works. In particular, the existence of the piles on a planned line of a shield tunnel would cause serious damage to the safety and the term of construction works. In this case, it is necessary to treat the existing piles safely and efficiently, but, any proper countermeasure cannot be found at present. Under the recognition above, we have developed an automated cutting system and a monitoring system to cut the obstructive section of piles on tunneling by using a water jet cutting method.

The features of these systems are summarized as follows:

- Introduction of the super high-pressurized abrasive water jet
- Development of the cutting system with automatic and remote control
- Cutting the piles precisely according to a programmed pattern
- Automatic control of the feed rate of abrasive
- Development of the monitoring system for the state of cutting
- Keeping the existing building in the original state by underpinning works

This paper reports on main systems, the results of experiments and the execution of cutting work.

2. OUTLINE OF SYSTEMS

2.1 WATER JET CUTTING SYSTEM

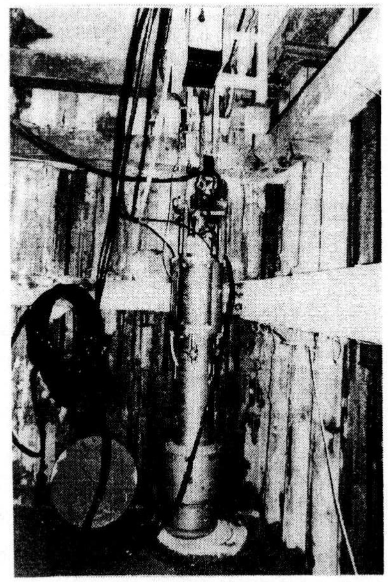

Photo. 1 Cutting capsule

The "Water Jet Cutting System" is the complex system in order to cut the PHC piles from the inner surface of its inside hole by abrasive water jet in full automatic and remote control. The abrasive water jet represents the high-pressurized water jet mixed with abrasive (grinding material). This system consists of six basic units ; a cutting capsule (cutting machine ; Photo. 1), a capsule elevator, a super high-pressure water pump, a supply device of abrasive, a compressor for feeding abrasive, and an operation and control equipment. Fig. 1 shows the "Water Jet Cutting System" composition. The cutting capsule is equipped with an abrasive water jet nozzle which can be driven through 360° freely by a servo motor. The capsule elevator, which perform the ascent and descent motion of the capsule, has the hoisting drum driven by a servo motor and the depth meter with a rotary encoder. Thus, the abrasive water jet nozzle can move horizontally, vertically or diagonally, according to the close positioning control by two servo motors, and its moving pattern can be determined arbitrarily on a computer program. The supply device of abrasive is set up to feed a required flow rate of grinding material into the abrasive nozzle, and the cutting ability of the abrasive water jet is sustained in good condition. Here, the feed rate of abrasive is regulated automatically in response to the measured value by a gate valve. Further, to insure the above feed rate, the flow rate of the compressed air dehumidified by a dryer is also adjusted to a constant rate. About the supply line of abrasive, we use one long tube with no joint in order to raise its wear-resistance. Moreover, the jet nozzle oscillates from the origin 0° to 363°, so that no twists of an abrasive tube, pressure hose and signal cables occur.

All units composing this system are automatically and remotely controlled by the operation and control equipment as shown in Fig. 2.

2.2 Monitoring System for the State of Cutting

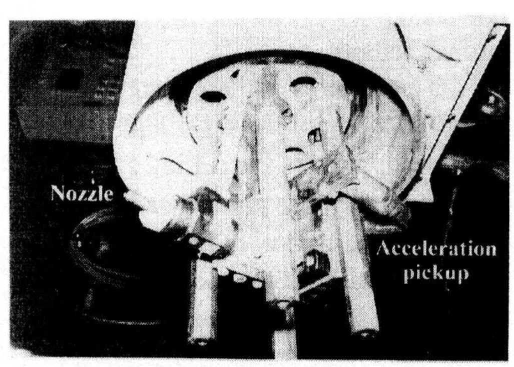

Photo. 2 Acceleration pickup

When applying the water jet cutting method to underground works, it is essential to monitor the states of the jetting and objects, so as to attain a complete cutting work. Thus, we have developed the monitoring system which is based on the measurement of vibration level. On the results of experiment, a remarkable change of vibration level at a specified frequency appears according as the jet piercing. This system consists of an acceleration pickup (Photo. 2) attached near the jet nozzle in the cutting capsule and the measuring instrument of vibration level. The wave form of vibration caused by the jetting is measured with the acceleration pickup, and then, the spectrum of the wave is analyzed by FFT analyzer. As a consequence, while at cutting work, comparing the detected vibration level with the standard level, obtained from the results of normal cutting work, operators can know continuously the conditions of the jetting and cutting, and prevent the cutting deficient state.

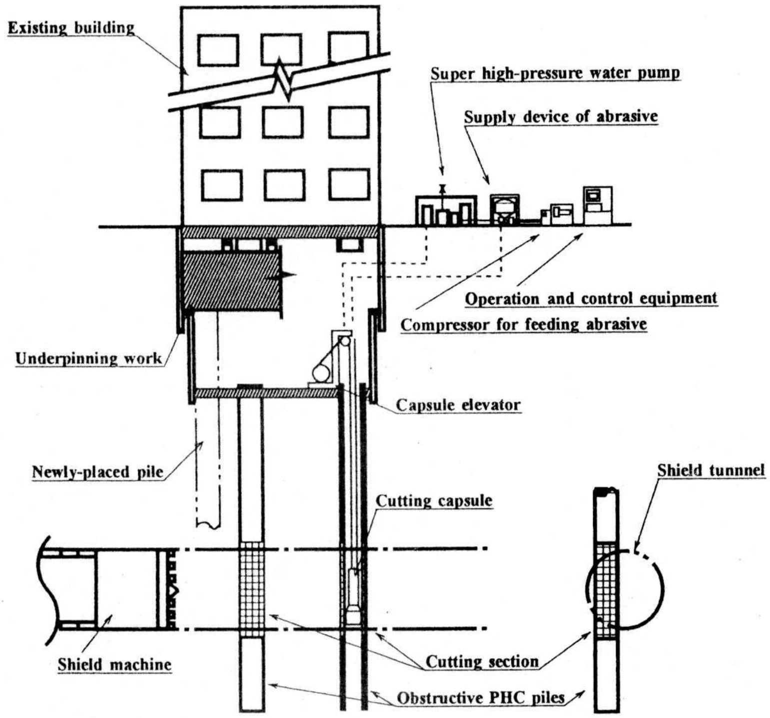

Fig. 1 Water jet system composition

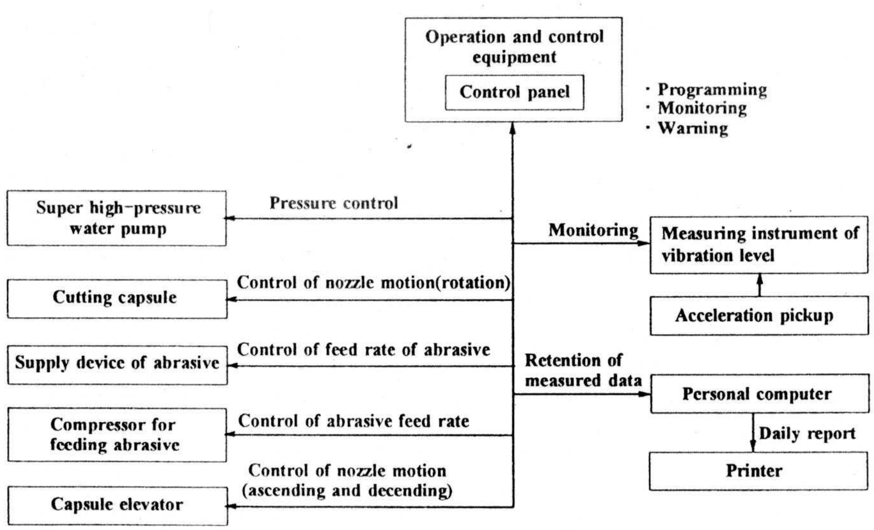

Fig. 2 System diagram

3. RESULTS OF BENCH TEST

There are many factors having an effect on the cutting performance of abrasive water jet as follows:

- discharge pressure
- nozzle diameter
- discharge flow rate
- type of abrasive and feed rate
- mixing efficiency of abrasive and water jet
- jet impact angle
- stand-off distance from nozzle to specimen
- traverse speed of nozzle

Table 1 Test conditions

discharge pressure	2320 kgf/cm^2
Flow rate	13 *l*/min
Type of abrasive	Garnet #60
Supply of abrasive	190 kg/h

In above factors, we can set flexibly the stand-off distance and the traverse speed, and it is important to adjust these factors to properties of a target. PHC pile consists of concrete and prestressing bars (steel), and cutting conditions suited to these materials are different from each other. As the prestressing bar is harder than the concrete, the cutting conditions have to be established so that the bar can be certainly cut into small pieces. Therefore, we performed the experiment of the PHC pile cutting on a bench in order to determine the basic conditions. The PHC pile has an internal diameter of 400 mm to 420 mm and an external diameter of about 600 mm, and the prestressing bar has a diameter of 9 mm.

3.1 STAND-OFF DISTANCE

First, we carried out the piercing test of the pile to optimize a stand-off distance from nozzle to specimen, and to grasp piercing time of the abrasive water jet against the pile. The test conditions are shown in Table 1. In this test, the stand-off distance is varied from 15 mm to 30 mm at 5 mm intervals, and the abrasive water jet nozzle is not driven. Fig. 3 shows the relations between the stand-off distance and piercing time when the water jet points to the part existing the prestressing bar and attacks it. As you can see, the piercing times for the stand-off distance of 30 mm vary widely. On the other side, considering the warp and uneven surface of the pile's hole, it is advisable to set the stand-off distance over 20 mm in a design. As a result, we use 25 mm as the suitable stand-off distance on basis of this test and the requirement on a design. About the piercing time, we gave 150 sec. well in advance.

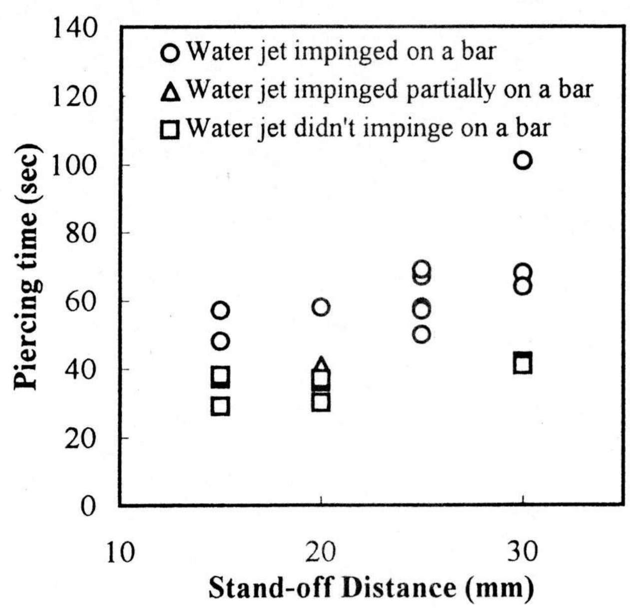

Fig. 3 Relations between piercing time and stand-off distance

3.2 TRAVERSE SPEED OF NOZZLE (CUTTING SPEED)

Next, to optimize the traverse speed of a nozzle, we also carried out the cutting test by moving nozzle at the stand-off distance of 20 mm and 25 mm. The nozzle was rotated about the pile axis and moved in the direction of the pile axis. The traverse speed was varied from 60 mm/min to 120 mm/min at 10 mm/min intervals. Table 2 shows these experimental results. From this, it was presumed that the upper limit of traverse speed was approximately 80 mm/min. As a result, we use 60 mm/min as the suitable traverse speed in order to obtain a stable cutting.

For grinding material, garnet and cast iron grid are used in this test. These materials are tested in the same conditions, but the prestressing bars could not be cut with cast iron grid.

When rearranging the results of this bench test, we can decide the cutting conditions of PHC piles as shown in Table 3.

Table 2 Results of cutting test
(○···good, ●···poor)

Traverse speed of nozzle	Stand-off distance at 25 mm	Stand-off distance at 20 mm
60 mm/min	○ ○	○ ○
70 mm/min	○ ○	○ ○
80 mm/min	○ ○	○ ○
90 mm/min		● ●
100 mm/min		● ●
110 mm/min		● ●
120 mm/min		● ●

Table 3 Basic cutting conditions

Items	Set values
discharge pressure	2500 kgf/cm^2
Traverse speed	60 mm/min
Stand-off distance	25 mm
Piercing time	150 sec
Dia. of jet nozzle	0.75 mm
Dia. of abrasive nozzle	7.00 mm
Feed rate of abrasive	200 ± 20 kg/h
Type of abrasive	Garnet #60

4. RESULTS OF FIELD TEST

As the next step, we performed a field test in full consideration of the results of a bench test. In this test, we placed PHC pile (7 meters long), of which the inside hole was filled with water, in the ground to the depth of 5 meters.

4.1 PATH OF CUTTING

It is necessary to cut the piles into small pieces under the size of 20 cm so that the pieces can be smoothly excreted in the soil through a shield machine. To attain this purpose, we planned two moving patterns of a nozzle, as shown in Fig. 4. Using A-pattern, the cut blocks are separated from the pile body quickly by the circumferential cutting. On the other side, using B-pattern, the cut blocks are separated in turns through the cutting work such as teeth of a comb. The cutting of A-pattern requires 63 minutes and that of B-pattern 70 minutes. It was proved in this test that both A-pattern and B-pattern had satisfactory cutting ability, but, we adopted A-pattern because of its efficiency.

The cut blocks obtained in this test are shown in Photo. 3. According to observation of the blocks, it was confirmed that the system was closely controlled along the programmed path. On the accuracy of the cutting, the cutting groove had about 5 mm wide and the blocks had an average height of 20 cm. On the width of a block, programmed at 18.8 cm, about ±1 cm error appeared. This error is due to the spin of the cutting capsule in the pile's hole. And hence, it was found to require improving the clamp force of the capsule.

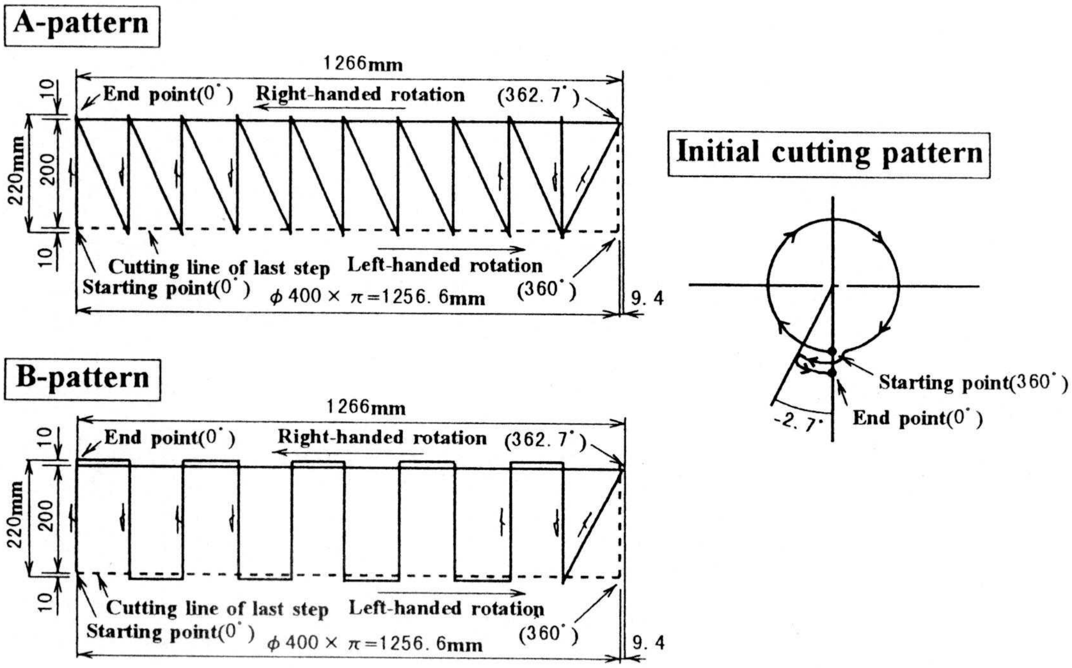

Fig. 4 Moving pattern of nozzle

4.2 MEASUREMENT OF VIBRATION LEVEL

From the measurement of vibration level, we observed 5 dB deference of the output at the frequency range of 4 kHz according with the change of the cutting state. On basis of this observation, we produced the monitoring system shown in Photo. 4.

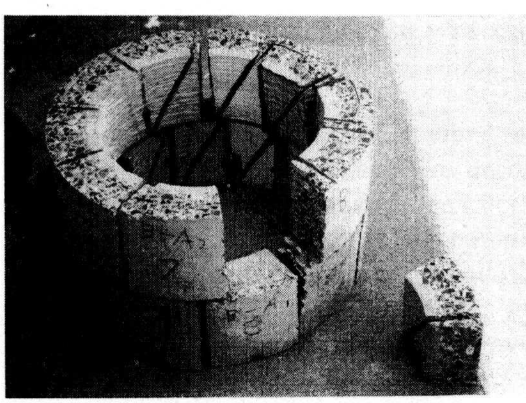

Photo. 3 Blocks in field test

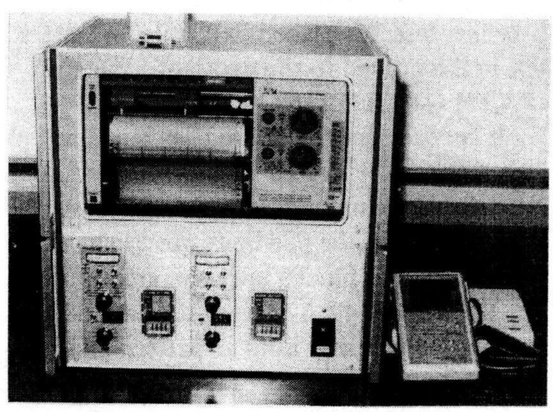

Photo. 4 Monitoring system

5. EXECUTION OF WORK

We applied the systems to the 11th construction area of the 7th subway line in Osaka. On this shield line, we met an obstacle due to 8 PHC piles. Table 4 shows the outline of the cutting works. The works made smooth progress, expect for excess deposition of the abrasive in the pile's hole. The deposited abrasive was removed timely by an air-lift pump. In consequence, we attained our purpose according to the cutting plan.

The shield machine passed without our catching the existence of that piles. About 4 % of all blocks were collected by a gravel storage box, and the others were crushed and excreted in soil through the pipeline of a soil pump. The cut blocks obtained in execution of work are shown in Photo. 5.

Fig. 5 shows the wave form of the monitoring system. In this work, we obtained significant signal in the range of 1 kHz to 3 kHz. Then, operators watched the vibration level in this range, and judged the condition of abrasive jet and the cutting state. Namely, in Fig. 5, when the vibration level approaches A level over the allowance of B level, we recognize that the cutting work becomes poor in spite of the impingement of water jet and abrasive. Further, when it drops C level under the allowance of B level, we find the deficient state of abrasive or the blockade of the abrasive feed line.

Table 4 Outline of cutting works

Pile number	Cutting length of pile(m)	Total length of cutting line(m)	Number of blocks
P14	6.2	122.20	310
P12	3.8	75.68	180
P10	5.6	110.64	280
P8	6.4	126.17	320
P7	6.4	126.17	320
P9	5.4	106.75	270
P11	4.4	87.33	220
P13	6.2	122.29	310
Total	44.4	877.32	2220

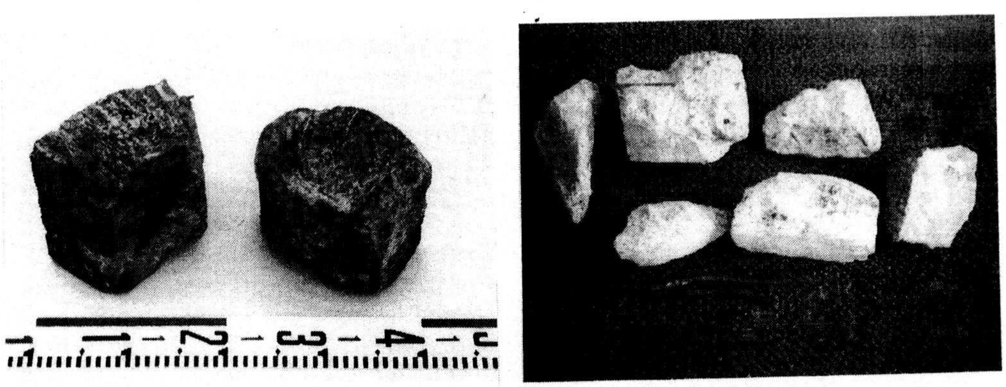

Photo. 5 Blocks in execution of work

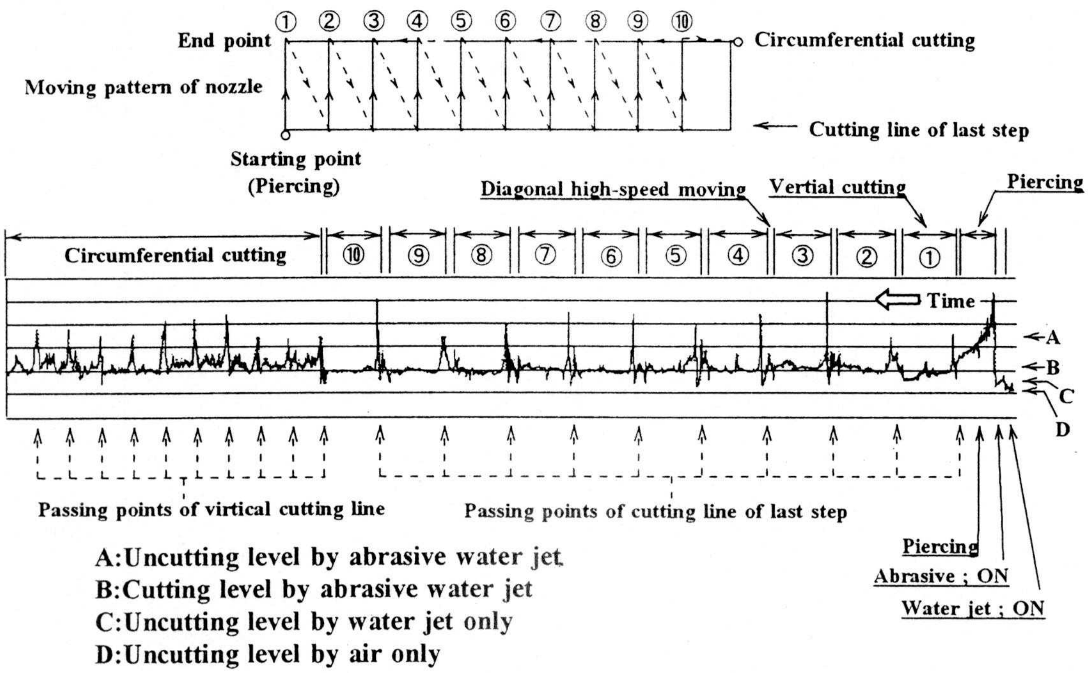

Fig. 5 Wave form of monitoring in execution of work

6. CONCLUSION

This paper describes an application of the water jet cutting method to a treatment for obstructive piles on a planned line of shield tunneling. In this application, we have developed the "Water Jet Cutting System" and the "Monitoring System" , and the execution of the work have satisfactorily done. These systems are the limited systems making use of the inner space of the piles, but, the treatment for obstructive piles have been rarely reported. We hope that this application will be used as a proper countermeasure.

In closing, we would like to express the sincere gratitude to KAWATETSU Transportation & Technology Co., Ltd. for their technical supports.