DEVELOPMENT OF BRANCH DRILLING AND CONNECTION DEVICE FOR PLASTIC GAS PIPE INSERTION METHOD

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ABSTRACT

Galvanized steel pipes that have been buried for 30 years or longer are at increasing risk of leakage caused by corrosion, and countermeasure methods and safety policies have been debated. In fact, active efforts to increase safety by the open cut method to replace these kinds of pipes with polyethylene pipes (PE) have been undertaken with a degree of success. But the inner pipes are assets of the customers although gas companies have the responsibility for their safety, and because the cost of their maintenance is borne by the customers, there is a strong demand for a lower cost improvement method in addition to replacing them with PE pipes by the open cut method. So in 2001, the Japan Gas Association whose members consist of city gas companies started a project to developing the plastic gas pipe insertion method as a less-excavation method that can lower the cost of pipe renovation.

This renovation method is executed by inserting plastic pipe, that is made of polyethylene, inside inner pipes (PE insertion method), but inner pipes often include many branch pipes. If a branch pipe were connected to main pipes by the open cut method, the cost of the execution would be almost the same as the conventional open cut method, significantly reducing the cost-benefits of this method. The solution to this problem is the branch drilling and connection device that is introduced in this report. This device is placed inside the main pipe that has been inserted where it can perform all operations—detecting the branch points automatically, drilling holes to insert the branch pipes, and connecting the separately inserted branch pipes to the main pipe—without excavation work. Installing and connecting branch pipes without excavation work effectively lowers the cost.
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1. INTRODUCTION

City gas companies in Japan have come to play an important role in providing energy to the nation by supplying gas to a total of 27 million customers including residential and industrial users. An examination of pipeline operation in Japan shows that the expansion of gas demand for industrial use and electric power production has increased the proportion of gas supplied in high and middle pressure pipelines, but because city gas companies in Japan originally supplied gas mainly for kitchen use and for heating water, low pressure pipelines make up more than 80% of the total of 22,000km of pipelines, and the maintenance of these pipelines is extremely important. And considering the fact that unlike the countries of America and Europe, in Japan gas companies have the responsibility for the safety of inner pipes, not only upstream from gas meters but also downstream from them and that inner pipes are laid underground in the customer’s premises, their maintenance is also extremely important for gas companies.

Of these, galvanized steel pipes that have been buried for 30 years or longer are at increasing risk of leakage caused by corrosion, and countermeasure methods and safety policies have been debated. In fact, active efforts to increase safety by the open cut method to replace these kinds of pipes with polyethylene pipes (PE) have been undertaken with a degree of success. But the inner pipes are, as explained above, assets of the customers although gas companies have the responsibility for their safety, and because the cost of their maintenance is borne by the customers, there is a strong demand for a lower cost improvement method in addition to replacing them with PE pipes by the open cut method. So in 2001, the Japan Gas Association whose members consist of city gas companies started a project to develop the plastic gas pipe insertion method as a less-excavation method that can lower the cost of pipe renovation.

This renovation method is executed by inserting plastic pipe made of polyethylene inside inner pipes (PE insertion method), but inner pipes often include many branch pipes. If a branch pipe were connected to the main pipes that have been inserted, by the open cut method, the cost of the execution would be almost the same as the conventional open cut method, significantly reducing the cost-benefits of this method. The solution to this problem is the branch drilling and connection device that is introduced in this report. This device is placed inside the main pipe that has been inserted where it can perform all operations—detecting the branch points automatically, drilling holes to insert the branch pipes, and connecting the separately inserted branch pipes to the main pipe—without excavation work. Installing and connecting branch pipes without excavation work effectively lowers the cost.

In this report, an explanation of the entire PE insertion method is followed by an introduction to branch drilling and connection device that is main theme of this paper.

2. THE OUTLINE OF THE WHOLE PE INSERTION METHOD

This method consists of five major processes: (1) the pipeline survey process that confirms the length and detail—number of bends for example—of the pipeline to be executed, (2) the main pipe insertion process that is the insertion of the PE pipe inside the existing main pipe, (3) branch point drilling process that drills holes at branch points, (4) branch pipe insertion process that is the insertion of the branch pipe, and (5) the branch pipe fusing process that is the fusing of the main pipe to the branch pipe (See Fig. 1). Process (3) branch point drilling process and process (5) branch pipe fusing process concern the Branch Drilling and Connection Device that is the main theme of this paper and are, therefore, discussed in detail later. This chapter provides outlines of the survey technology and the main and branch pipe insertion processes.
2.1 Preliminary Pipe Survey Process

This method, as explained below, has a restriction on the total length and number of bends, so it is essential to accurately clarify the total length of the pipe and the number of bends in advance in order to confirm that the method can be applied. To increase customer satisfaction, the survey work should be performed in as short a time as possible. As technologies that satisfy the demands for “the accurate clarification of the detail of the piping” and “shortening the work time” to a high level, we have developed three technologies, the in-pipe camera, ground penetrating radar, and ultrasound surveying device that can be used inside a live pipe. The survey is done by taking advantage of the characteristics of various technologies by combining them suitably so that an accurate survey can be performed in the shortest possible time.

2.1.1 In-pipe Camera

This camera is a pipe survey technology that can be applied inside complicated pipes with branches, and a camera mounted on its tip can clarify the state of the interior of a pipeline (diameter, bends, etc.). This device can be inserted from the pipe end after the gas meter has been removed, so basically it is unnecessary to cut the pipe. And it is designed so it can be used for execution in live pipe status. Therefore work time is extremely short. The major feature of this device is that permits the worker to visually check the detail and status of the pipe, so he can accurately understand its condition. (See Fig. 2)
2.1.2 Ground Penetrating Radar (GPR)

This radar is technology that clarifies detail of the piping by directing radar from the ground surface, permitting a survey without any excavation. Its software automatically estimates the diameter and location of the buried pipeline, permitting the operator to perform the survey easily without requiring special skills. (See Figs. 3,4)

![Fig.3 Conventional(left) and New(right) GPR](image1)

![Fig.4 GPR (monitor is closed)](image2)

2.1.3 Ultrasound Surveying device

This surveying device uses ultrasound and is intended to survey “simple pipes” (i.e. piping without branch pipes). It picks up the reflected ultrasound waves generated from the signal generating and receiving head to detect the detail of the piping. Although this device cannot be applied to “complicated pipes” (i.e. piping with branch pipes), it can confirm detail of the piping with branches as hot work, permitting the survey to be completed in a very short time. (See Fig. 5)
2.2 PE Insertion Process
This process is the insertion of the PE pipe into the main pipe. As shown in Figure 6, insertion is done by pulling the PE pipe in from the opposite pipe end using a winch, but in the straight section from the pit to the first bend, a smooth pipe is used, and in the main pipe beyond the first bend, a corrugated pipe is used because flexibility is required in this section. Therefore, it is necessary to appropriately connect the corrugated pipe and smooth pipe in advance to match the detail of the piping revealed by the preliminary pipe survey process.

Afterwards, branch points in the main pipe are drilled with the Branch Drilling Device, then the corrugated pipe that is used for branches is inserted from inside the main pipe. The connection between the main pipe and the branch pipe is the Branch Connection Device that is connected by fusing the connection points.

The above are overall system configuration and the execution flow, but this paper will provide detailed explanations targeted on the Branch Drilling Device and the Branch Connection Device that are technologies with a key role in reducing costs.

3. BRANCH DRILLING AND CONNECTION DEVICE
This method is applied as a corrosion and leak countermeasure on galvanized steel pipes, but its major purpose is, as stated above, cost reduction. The most effective cost reduction method is reducing the number of excavation, so if it were possible to reconnect branch pipes without excavation...
work, it would be possible to expand this cost benefit. The solution to this matter is the Branch Drilling and Connection Device introduced by this paper; a device that can be used to reconnect branch pipes without excavation work.

It consists of two devices: a Branch Drilling Device that drills the branch points on the main pipe and the Branch Connection Device that connects the main pipe to branch pipes, and these are collectively called the Branch Drilling and Connection Device. The structures of the Branch Drilling Device and the Branch Connection Device are described separately below.

3.1 Branch Drilling Device
3.1.1 System Configuration
This device consists of the Branch Drilling Device that actually drills holes in the pipe, a cable that transmits electrical power and signals, a cable drum that coils and holds the cable, the controller that controls the Branch Drilling Device, and the monitor that displays images taken by a camera that is mounted on the Branch Drilling Device to confirm the quality of the drilling work (See Fig. 7). On this device, the microprocessor installed on the controller analyzes signals from the Branch Drilling Device, filling a role as the controlling brain, in order that detailed hole positioning, movement and drilling are performed automatically.

In addition, it requires a power source to provide drive power, and the electrical generator used for the PE insertion process can also be diverted for this purpose, so it is not necessary to prepare an electric power source specialized to power this device.

3.1.2 Branch Drilling Device Configuration
The Branch Drilling Device must have a drilling function that drills holes, a branch point detection function that detects branch points, a traveling function that moves the drill unit precisely to the branch location, and an observation function that observes the drill location, and it must be equipped with electronic circuits that control these functions. But the internal diameter of the smooth pipe that is the object of the execution by this system are small diameters of 44.8mm and 68.3mm, so it must be stated that it is extremely difficult to collect and install these functions in one place. Therefore, the drilling function, traveling function, and observation function are installed in the processing unit and the control use electronic circuits are installed in the control unit by installing them in a line in the axial direction of the pipe.

On the Branch Drilling Device, these units are, as shown in Fig 8, connected with a hinge-equipped bending structure so that it can be inserted easily from the pit.
3.1.3 Functions of the Processing Unit

Fig 9 is an outline of the processing unit. As explained above, the processing unit consists of a drilling function, branch point detection function, and moving function, but the drilling function is an optical head that actually drills holes at branch points on the main pipe. The system drills by cutting holes on the main pipe with a laser beam radiated from the optical head, but because the holes must be circular to match the shape of the branch pipes, a pipe lengthwise direction motor and a rotating shaft motor are both installed to move the optical head in the pipe lengthwise direction and the pipe peripheral direction, and a controller operates these automatically to correctly drill the holes. And the pipe lengthwise direction motor and the pipe rotating shaft motor also play roles as the traveling function to move the optical head to the branch points that have been clarified.

Magnetic sensors are installed at two locations to detect branch locations. These sensors detect magnetism produced by targets that are installed in the branches in advance to detect the branch points. One is at the tip of the device and the other is close to the optical head. The magnetic sensor at the tip of the device is installed to clarify the approximate branch location, and it operates when the device is inserted manually close to a branch point. The magnetic sensor that is installed close to the optical head is used for fine positioning, and it is used to clarify the final hole location.

And during drilling, it is necessary to accurately drill the hole, so an air picker is installed at the tip of this device because it is necessary to anchor the unit solidly inside the pipe. The device can be anchored during drilling by inflating the picker with air.

![Fig.9 Outline of the processing unit](image)

3.2 Branch Connection Device

3.2.1 System Configuration

This device consists of the Branch Connection Device that connects branch pipes to the main pipe, a cable that transmits electric power, a cable drum that winds and stores the cable, a high frequency power source that produces a high frequency current that flows through a coil installed inside the Branch Connection Device and a cooling device that supplies chilled water to cool the coil. (Fig. 10).

In addition, an electrical generator is necessary to provide electric power to the system, but like the Branch Drilling Device, it is not necessary to provide another power source unit, because it is possible to use the power source for PE insertion.

![Fig.10 Branch connection device system configuration](image)

3.2.2 Branch Connection Device Configuration

This device applies the inductive fusion method: heating the connection coil installed at the end...
of the branch pipe (Fig. 12) with an induced magnetic field. Therefore, the device must at least have a
high frequency coil that produces an induced magnetic field in the center of the connection coil, but in
addition, it is also equipped with an air bag that pushes the high frequency coil and the connection coil
that is to be connected against the inner surface of the smooth pipe, and a silicon rubber sheet that
narrows the space between the high frequency coil and the connection coil to ensure uniform surface
pressure.

But in order to perform appropriate connection, this alone is insufficient; it is also necessary for
the high frequency coil to be accurately centered in the connection coil during connection. Therefore it
is designed with a Kevlar wire that passes through the center of the high frequency coil so that the high
frequency coil can be automatically positioned in the center of the Connection coil by pulling this wire
from the end of the branch pipe.

![Diagram of Branch Connection Device](image)

![Connection coil](image)

### 3.3 Scope of Application

The following are the specifications of this device.

<table>
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<th>Table 1. Specifications of the device</th>
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<tr>
<td><strong>Main pipe diameter</strong></td>
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<td><strong>Branch pipe diameter</strong></td>
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<td><strong>Traveling distance</strong></td>
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<td><strong>Size of pit</strong></td>
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The diameters of the main pipes handled by this device are 50mm and 80mm, and it can be
executed for a maximum distance of 20m from a pit. Therefore, although its use is limited to straight
pipe, it can be executed in a maximum section of 40m by inserting the device in both sides from the pit.
Considering the fact that the pipes that are executed using this insertion method are inner pipes on
customers' premises, this is assumed to be adequate execution length.
4. EXECUTION PROCEDURE

The functions of this device are as explained above, but the execution procedure is explained below to show how this device is actually used. The Branch Drilling Device uses magnetic sensors to detect branch points, but in order for it to do this, magnets or other devices that produce magnetism must be installed at branch points in advance. This is done by installing targets with magnets on their tips at branch pipe points in advance. The targets are equipped with air bags that are inflated with air, and with these air bags inflated, the targets are positioned correctly at branch points by being pulled to the branch pipe side from the main pipe. (See Fig. 13 (a))

After insertion in the main pipe, the Branch Drilling Device is used to drill holes at branch points. This device is inserted manually, but it is inserted to approximately the branch point while checking the output of the magnetic sensor on the tip of the device. Then the device automatically performs the series of steps, detection of the correct branch point, movement of the optical head, and drilling. Therefore the operator does not have to operate the device during this operation. (See Fig. 13 (b), (c))

Then after branch pipe insertion has been done, the connection process that connects the branch pipe to the main pipe is performed, but this process is done using the Branch Connection Device (See Fig. 13 (d)). Finally the Branch Connection Device is pulled out and the air tightness is checked completing the process.

As stated above, this device drills each branch point from inside the main pipe and connects the branch pipe to the main pipe, without excavation work. Therefore, the work can be done with much greater simplicity and much faster than by excavating the ground to connect each pipe.

Fig13. Device operating procedure
5. COST BENEFIT

This concludes the explanation of the functions of the method, but an explanation of the cost benefits of introducing this device follow. Fig.14 shows the results of applying a certain model case to compare the costs of three patterns: PE pipe replacement by the conventional open cut method, PE insertion method without this device, and PE insertion method with this device. It shows the relative cost of the PE insertion method without this device and the PE method with this device when the cost of the conventional open cut method is assumed to equal 100, revealing that large cost reduction effects can be achieved by combining this method and this device.

The trial calculation was performed for a pipe with many straight sections and with many branches that are sections where this method is particularly beneficial, but there may be cases where, according to piping, the cost is lower if the branch pipes are connected by the open cut method instead of using this device.

Therefore when planning to actually apply this method, it is necessary to first compare it with the PE pipe replacement by the conventional open cut method and the PE insertion method without this device to estimate which will provide the greatest cost reduction.

6. CONCLUSION

Above, the Branch Drilling and Connection Device that drills and connects branches when applying the PE insertion method has been explained. The following conclusions have been made.

- We have successfully developed a Branch Drilling and Connection Device used to perform branch pipe connections to apply the PE insertion method.
- This device can be used in pipes with extremely small diameters of 50mm or 80mm.
- This device can sharply reduce the costs of the PE insertion method by drilling branches and connecting branch pipes very quickly without excavating.

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