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Pipe-jacking/micro-tunneling technology in Japan and the development of a new micro-tunnel boring machine (MTBM)

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ABSTRUCT

Demand for installation of various pipes/cables in underground is growing due to the rapid urban development in recent years. The common construction methods are open-cut, pipe-jacking, and shield-jacking. It is generally said that shallow pipelines should be constructed by the cut-and-cover method, and deep pipelines might be carried by using a trenchless method. In Japan, when carrying out underground pipeline installation, due to heavy traffic conditions and increasing numbers of underground utilities, the pipe-jacking/micro-tunneling method in urban areas has replaced the conventional cut-and-cover method. This method has been achieved remarkable progress with the development of technical infrastructure. Today's pipe-jacking/micro-tunneling technology in Japan has been firmly established as a special method for non-disruptive construction of underground pipelines for sewage, water supply, telecommunications, electricity, and gas. As the pipe-jacking /micro-tunneling method has made technological innovations, it becomes available for pipe-line construction of larger diameter, longer drive length with more accuracy by using laser guided targeting, etc. Additionally, the development of effective, appropriately designed utilization of deep ground is also strongly encouraged due to increasingly complex shallow utilities.

This paper discusses the development of pipe-jacking/micro-tunneling technology in Japan, the development of a new micro-tunnel boring machine (MTBM) and its new applications.

INTRODUCTION

In the 1950s, there was no sewer system in Japan. Therefore, waste water/sewage from each family or building was generally discharged into the drains and river system. And some people dumped their domestic trash or garbage into rivers. So, the environment in urban areas was very bad. As a result, the river water was naturally polluted severely. After introducing the sewer network and sewage treatment plant system, the conditions of river water were improved remarkably and the river ecosystem has almost recovered as before. Now, people can enjoy their healthy and sanitary life. Pipe-jacking/micro-tunneling technology have played an important role in constructing the sewer network in Japan. Recently this technology has been progressed to meet the modern challenging of underground construction in urban areas.

This paper discusses the development of pipe-jacking/micro-tunneling technology in Japan, the development of a new micro-tunnel boring machine (MTBM) and its new applications.

DEVELOPMENT OF SEWER PILELINE INSTALLATION SYSTEM

For pipeline installation, there are two methods. One is the cut-and-cover system, so-called open trench system and the other is machine tunneling system such as pipe-jacking/micro-tunneling system. The cut-and-cover system is an easy and cost-effective method. However, this system is just for shallow depth up to 6 m. For deeper depth or heavy traffic conditions, machine tunneling system is mainly used in Japan. In the machine tunneling system, there are two systems; one is the shield-jacking and the other is the pipe-jacking/micro-tunneling system. In shield-jacking, pipes are assembled from segments just behind the cutting machine. Pushing jacks are just behind the cutting machine. In pipe-jacking/micro-tunneling system, cutting machine and pipes are pushed by jacks installed in the driving shaft.

The term of "micro-tunneling" means here that the tunnel diameter is small, roughly 37.5-420 cm and the remote controlled system, no-man-entry and laser guidance system are adopted. Recently over 5 m diameter pipeline tunnels have been constructed using the same technologies.

First pipe-jacking work in Japan was conducted in 1949. The 50 cm dia. and 6 m long steel pipe was installed by the pipe-jacking method. Since then, the

system and machines have been improved and developed. Now over 1 km-long, over 5 m dia. and small curvature pipeline installation is possible using pipe-jacking/micro-tunneling system. These results have been established by development of new machines, reinforced concrete pipes, lubricants and razer guided navigation systems.

Under stable ground conditions, open face type tunneling system is often used. However, stable ground is rare, and unstable conditions are normal in Japan. Considering unknown and difficult/complicated ground conditions, in order to maintain face space during face cutting, closed face type shield machine or micro-tunneling system was developed and introduced. At the planning stage of the project, geological survey is carried out by check boring or seismic survey etc., but it is difficult or impossible to understand the perfect conditions. Therefore, it is better to introduce almighty tunneling machines that are applicable to a wide range of ground conditions. Table 1 presents the machine selection method considering the ground conditions and tunnel machine size. This is based on the Iseki Uncle Mole machine experiences.

Up to now, over 447,000 km long sewer pipeline has been constructed in Japan as shown in Figure 1. This length reached over 11 times of the Earth's circumference. However, the pipeline installation work has been decreased these days, because sewer pipeline installation is almost completed in urban areas. The sewage coverage has already reached 77.8%. Due to the aged deterioration of sewer pipe that is over 30 years old, pipe renewal works have been brisk these days.

In big cities, the more use of underground space is required, many plans are proposed and some project have already started. In those projects, larger or more complicated underground spaces are requested. Pipe-roofing using micro-tunneling system is aggressively introduced as a secure construction system for large or complicated underground space. However, the underground in urban areas is already congested by many underground utilities.

STOPPAGE OF TUNNELING WORK

Before starting the project, all systems used in pipe-jacking/micro-tunneling are selected considering project conditions and ground conditions. Two shafts

are generally constructed for pipe-jacking/micro-tunneling project; the launch/driving shaft and the reception/receiving shaft.

Geological survey is usually performed before starting the project. However, it is difficult or impossible to understand the detailed information about the ground conditions along the project site. In some cases, machine tunneling has to be stopped during operation due to the sudden change of ground conditions occurring the hard rock layer, gravels with cobbles or boulders or mixed conditions, the occurrence of unforeseen obstacles such as steel sheets/piles, concrete piles, concrete blocks etc. and heavy failure or wear of cutting tools or cutting wheel.

Many efforts are done to cut through the obstruction. If the stable ground and no groundwater conditions, workers could work in the cutting face or the cutting wheel space inside the tunnel machine. If impossible, the machine has to be recovered from a rescue shaft constructed for recovery. However, if there is no space for the rescue shaft due to an existing building, freeway, rail road or river, in the worst case, the project will be cancelled and the machine will be also abandoned.

In these days, construction of larger and more complicated underground space is planned and some are already started using the pipe-roofing in urban areas here in Tokyo and Osaka, Japan. The underground in urban areas is already congested by many underground utilities. Considering these conditions, a new machine has be developed.

DEVELOPMENT OF A NEW MICRO-TUNNEL BORING MACHINE (MTBM)

Generally, a pipe-jacking/micro-tunneling machine is applicable for a wide variety of ground conditions from sand, or weak/soft soil to hard soil or rock layer, or gravels with cobbles and boulders or mixed ground. However, due to unforeseen ground conditions or obstacles, tunneling work sometimes has to be stopped. In order to solve the problem, the following steps are considered basically:

Step 1: Drive stop

Monitor/identify the obstacle via a CCD camera that is inserted in the observation ports.

Step 2: Ground improvement

Improve the ground at the face and around the MTBM by injecting the chemical grout to stabilize the face and prevent water inflow.

Step 3: Obstruction removal

Pull back the MTBM and remove the obstacle.

Step 4: Redeploy the MTBM and drive again

Push back the MTBM and start driving.

A new machine, a slurry-type MTBM, was developed by Iseki Poly-Tech as a solution to the problems that come with operating in confined space as shown in Figure 2. Its unique feature is its ability to pull-back and redeploy in the same bore. During this process, the soil at the face of and around the machine is stabilized and paths of water inflow can be cut-off using chemical grouting as shown in Figure 3.

The geological condition and any unknown obstructions in the tunnel face can be observed via a charged coupled device (CCD) camera that can be inserted through observation ports as shown in Figure 4. In addition to this, for extended drives in hard rock or gravel with boulders, using the pull-back mean that the cutter head can be replaced during the drive.

Iseki Poly-Tech developed the machine after it found that the diameter of the closed-face MTBMs is often so small that it is extremely difficult to continue boring when facing unforeseen obstructions on the intended alignment. This issue has been solved through the addition of the feature that allows the machine to be pulled back and redeployed early after the removal of obstructions.

When the MTBM is pulled back, the dimension of the cutting wheel needs to be reduced because the outer diameter of the face is slightly larger than that of the pipe diameter. To accomplish this, all the cutter bits of the cutter periphery are folded inward to reduce the diameter by pulling back the center-axis rod of the MTBM as shown in Figure 5.

This feature allows the MTBM to arrive at an existing building or pipeline without the need for an arrival shaft as it can be pulled back to the starting shaft after a drive. The MTBM can be reset into the same bore or can be used for other drives or projects.

When the MTBM is pulled back, the collapse of the tunnel face and the surrounding ground can be prevented through the use of chemical grout that is injected from inside and around the machine, known as the over-cutting

area that aims to stem water inflow and improve the ground as shown in Figure 3. The chemical grouting, at the face and around the machine, normally uses silicate based grouts.

When starting the next drive, the outer diameter of the cutting wheel is expanded to the original size by pushing the center-axis rod as shown in Figure 5. The machine has the ability to be deployed on steel pipes, but also on thicker walled reinforced concrete pipes too.

This new machine won the ISTT NO-DIG AWARD (New Machine Award) 2016 in Beijing.

SOME APPLICATIONS OF THE NEW RETRACTABLE MTBM

Some applications of the new retractable MTBM are as follows:

Case 1: Construction of pipe-roofing from starting shaft for large size space or tunnel

Case 2: Construction of portal of mountain tunnel using pipe-roofing.

Case 3: Connecting the branch pipe to the existing sewer main or underpass tunnel below the existing building without the reception shaft.

Case 4: Unexpected underground obstacles, in this case the obstacle can be removed from inside machine as above-mentioned.

Case 5: Changing cutter bits/repair the cutter head in long drive in hard rock.

Case 6: No-working place at arriving spot such as steep cliff.

Case 7: Connecting two tunnels.

CONCLUSIONS

Closed face MTBM has been developed and provided for a variety of unstable ground conditions. It is important that the small diameter MTBM has more challengeable conditions than large diameter. It should be significantly considered that closed face MTBM in small diameter is used in difficult conditions such as in curved alignment, long distance drive, in complicated ground conditions and management for underground obstacles.

It is very difficult and costly to comprehend the nature of the soils, rocks and unforeseen underground obstacles at the whole location of the project. The

new MTBM for pull-back and redeploy above-mentioned can be used in case of undetected obstacles or complicated ground conditions.

If you are interested in this machine and technology, visit www.isekimicro.com for further information.