Application of Pipe Jacking Technology into ASEAN Countries

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Demand for installation of various pipes/cables in the 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 installed 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 methods in urban areas have replaced the conventional cut-and-cover method. This method has achieved remarkable progress with the development of the appropriate technical infrastructure. Today's pipe jacking 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 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 strata is also strongly encouraged due to increasingly complex shallow utilities. This paper will discuss the development of the pipe jacking method in Japan and its expansion into ASEAN countries.

1. INTRODUCTION

In Japan, over the past few decades, utility construction in the underground such as water supply lines, sewage disposal networks, gas supplies, and cable systems for power and communication has developed progressively (Shimada, Kawai, and Matsui, 2009). In the past, when constructing in the shallow strata, open-cut methods were widely used because construction had to be precise, reliable, and economically efficient. However, due to the neighboring construction, it is difficult to secure road traffic, prevent construction hazards such as vibration and noise, and protect the existing congested underground installations. In addition, the pipe jacking method has been widely adopted as a general construction method owing to its recent marvelous technological development (Japan Tunneling Association, 1997).

2. WHAT IS THE PIPE JACKING METHOD?

Pipe jacking technology, that is one of the trenchless methods for installing a rigid pipe segment through the ground from a launching shaft to a reception shaft, is a widely employed alternative to the cut-and-cover method. The method provides a flexible, structural, watertight, finished pipeline as the tunnel is excavated. This technology was developed in the United States over 50 years ago. Since that time, the advantages of this method have been recognized by the entire world. An illustration of the pipe jacking system is as shown in Figure 1.

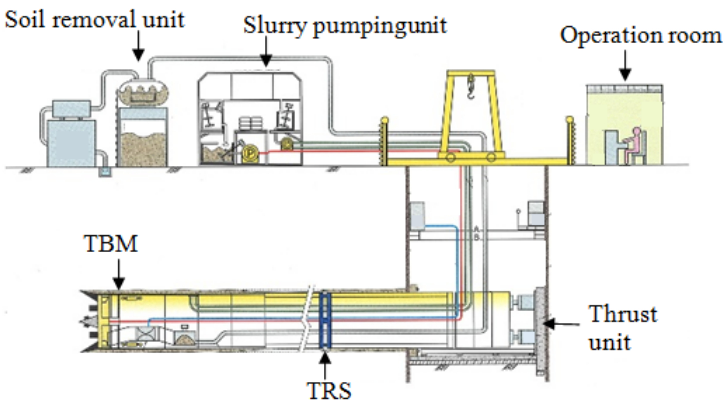


Figure 1. System of a pipe jacking method.

The pipe jacking construction is best employed in stable, water free soil conditions. Unfortunately, with the demands on available space and the need to provide more services, it is not always possible to select stable strata. Recent technological developments have led to the ability of stabilizing unstable ground strata by eliminating water from excavation by means of placing mud slurry around the pipes and using it to support the excavation face. Slurry pipe jacking is one of the best construction methods for making a tunnel both in unstable strata and water free soil conditions. Figure 2 shows an illustration of the pipe and the soil in this system.

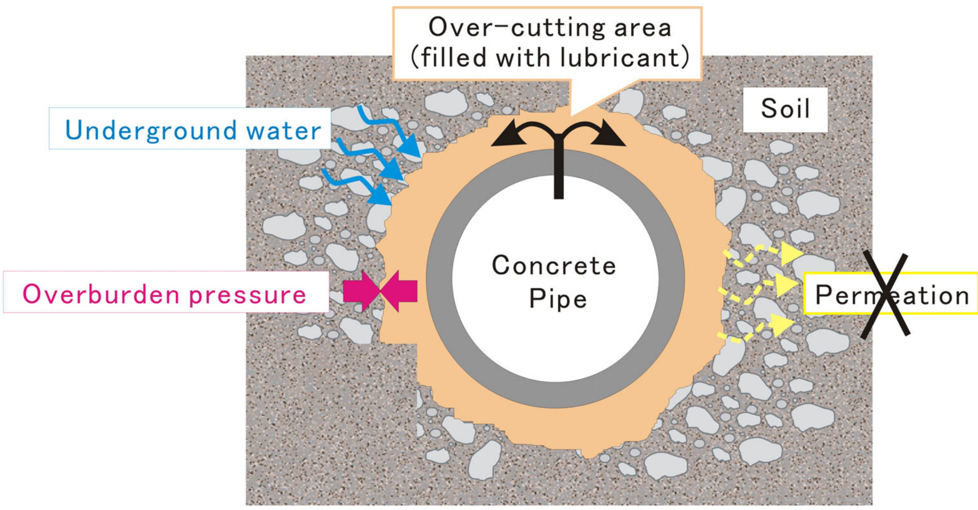


Figure 2. Illustration of a concrete pipe and soil.

3. CLASSIFICATION OF PIPE JACKING METHOD

There are many pipe jacking methods that can operate in a variety of ground conditions, from hard rock to soft water-bearing ground. Moreover, it is classified by some factors such as pipe diameter range, drive length, excavating system, cutting face support, and excavated material haulage system. It is difficult to change jacking methods due to an inoperable situation once a project begins. Therefore, the right method has to be chosen. Each technology has undergone innovation in order to overcome many problems of difficult conditions. There are several excavating systems depending on ground conditions, such as hand-excavating, full-face or partial excavation. The mechanical types with full-face are called as closed-face type pipe-jacking. The excavated materials are typically removed from the tunnel using a slurry circulation system, or the screw conveyors to the jacking shaft and muck-cars or continuous augers, depending on the excavating system. Accuracy is monitored by various laser targeting systems, and hydraulic rams are attached to the shield to allow steering in all directions. Under these circumstances, the pipe jacking system is classified as shown in Figure 3.

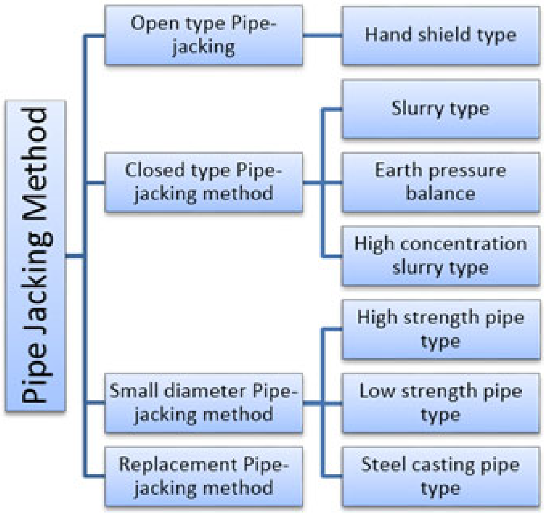


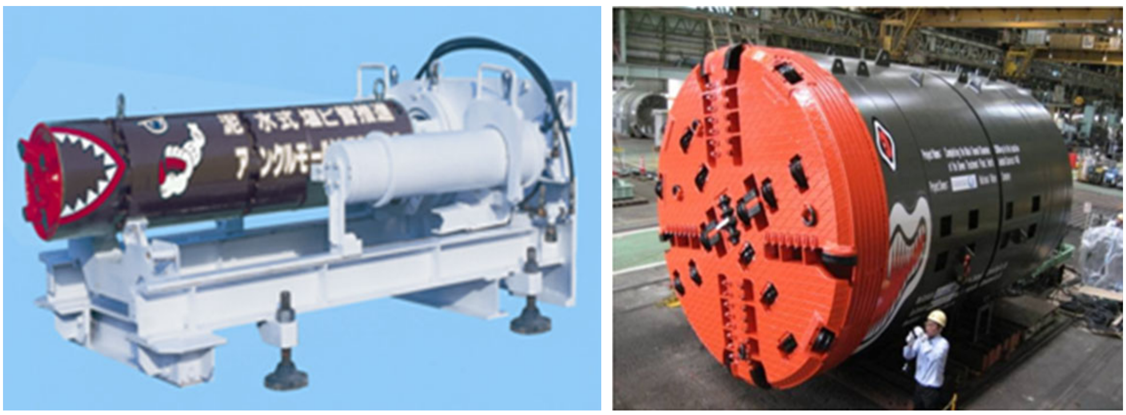
Figure 3. Classification of pipe jacking method.

4. RECENT PIPE JACKING TECHNOLOGY IN JAPAN

Several closed-type jacking methods are adopted in Japan because they enable construction that accounts for the possibility of collapse and for underground water pressure of the earth and sand in the surrounding areas, thereby facilitating safe digging.

A. Pipe Jacking Diameter

A jacking method within the range of φ150 mm to 3,000 mm in diameter is used in Japan. (Recently, the range of 3,500-5,000 mm has also been possible). Japanese law prohibits from working inside of the pipe in case of the inner diameter of the pipe less than 800 mm. According to Japan Tunneling Association (JMA), the method is called “large diameter” in case of more than 800 mm, and “small diameter” for less than 800 mm. Figures 4 (a), (b) show a small diameter excavator and a large diameter excavator of pipe jacking. A special ferroconcrete pipe is generally used in the pipe jacking method. Steel and ductile pipes, as well as other types of pipes, are used for other purposes.



(a) Small diameter (b) Large diameter

Figure 4. Jacking machine of pipe jacking.

B. Drive Length, Curve Pipe Jacking

The pipe jacking method can construct lines over long-distances by using a few inter-jack stations in the intermediate points of the line and some other technologies. The possible length of line constructed in single drive ranges generally from 300 to 600 meters. A 1.3 km line has also been constructed, the longest yet in Japan (Hirai, Sato, and Shimada, 2013). However, the permissible construction length is decided according to the diameter, the strength of jacking pipe and some other construction conditions.
On the other hand, the possibility of curved pipe-jacking construction depends on the diameter, the nature of soil, and some other jacking technologies including overcutting, lubrication and laser guidance system. The most important technology for long drive and curved jacking is the tunnel alignment measuring system using the laser target. Pipes can be driven in a range of directions from a straight line, to a radius, or a series or radii via a number of excavation systems that include manual, mechanical, or remote control. Pipelines are being installed in ever increasing lengths through a multitude of geological conditions due to the implementation of a few inter-jack stations and automated lubrication systems, and with the use of laser guidance systems within the moving jacking pipes, curved lines down to 20 m radius are now achievable. Figure 5 shows the completed project map of long and curve pipe jacking.

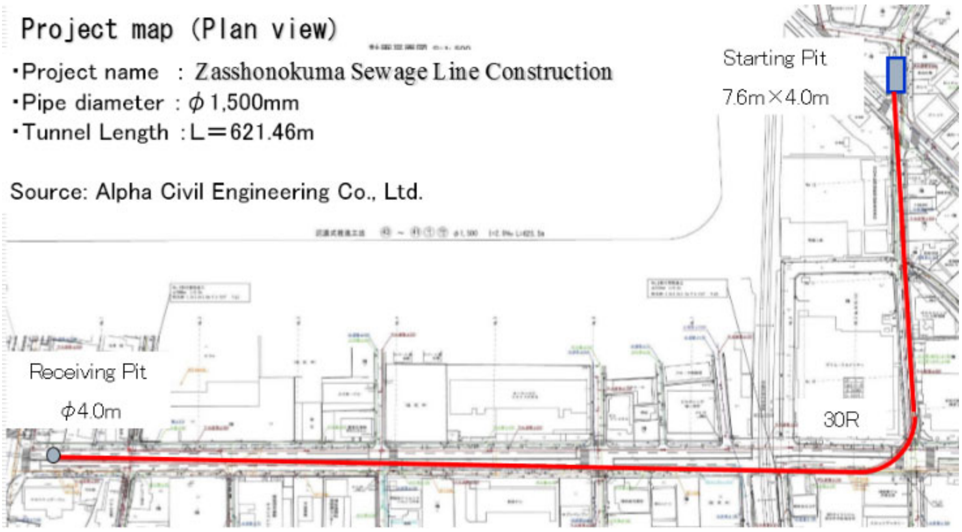


Figure 5. Construction map of long and curved pipe jacking.

C. Box Culvert Pipe Jacking technology

Recently, various infrastructures are buried underground, and the effective use of underground is demanded. From this situation, demands of the pipe line construction using rectangular pipes are increasing gradually. To fulfil with these demands, the Box Culvert Pipe Jacking Method was developed and has been used for rectangular pipe line construction. Box jacking is similar to pipe jacking, but instead of circular shaped jacking pipes, rectangular shaped pipe is used for pipeline construction.
The advantages of rectangular pipe over circular pipe include a larger effective cross-sectional area and reduced maintenance effort. The disadvantage of rectangular pipe has been the difficulty in mechanized installation. To cope with this challenge, the rectangular pipe jacking machine that has a face structure consisting of three rotating shafts each equipped with cutters at varying positions was developed in 2007. The use of this machine for infrastructure construction in Japan is slowly but surely increasing (Matsumoto et al., 2010). Figure 6 shows rectangular pipe jacking machine and Figure 7 shows the rectangular pipe jacking construction.

Figure 6. Rectangular pipe jacking machine.

Figure 7. Construction of rectangular pipe jacking.

5. UNDERGROUND SPACE DEVELOPMENT BY PIPE ROOF METHOD

The pipe roof method has been attracting the attention of engineers as a supplementary construction method of underground structures in Japan. This method has been widely recognized as an alternative for tunnel construction in urban areas to reduce adverse effects on underground utilities and ground surface activities. Ground behavior, pipe roof characteristics, and construction sequence have significant influence on the ground movement in the tunnel construction. Therefore, the pipe roof method is designed to minimize the potential threats in tunnel construction and has been successfully used in underground space directly beneath buildings, highways and railways.

Methods of pipe roof construction can be classified into three types; horizontal boring, auger, and slurry type pipe jacking. Recently, there has been an increase in the slurry jacking in pipe roof construction. The aim of using slurry pipe jacking with the pipe roof method is to extend tunneling operation in the most demanding conditions, such as non-cohesive soils, working in presence of ground water, limitations in surface settlement and different overburden depth. The pipe roof method has been found to be superior in the maintenance of ground stability, and in Japan there are many results by this slurry pipe jacking method. Figure 8 shows the tunnel with pipe roof construction method.

Figure 8. Tunnel entrance with pipe roof method.

Recently, applications of the pipe-jacking for the pipe roof method are often carried out, as supplemental linear tunnels by using iron pipes can be easily made by pipe-jacking before a main tunnel extraction. In this case, a retrievable drivage machine from the starting position is adopted for the pipe roof construction. The following are the characteristics and strong point of this method. By the pipe roof method by the small shield machine with control of the pressure of cutter face using the slurry pipe hacking, the cutter face condition consists of the mixture of high density slurry and the digging soil that have high fluidity in the range from a plasticity limit to a liquid-related limit.

Then excavating continuously with keeping the pressure of the cutter face over water pressure plus 20kPa can make the soil less permeability and secure dynamic stability of the soil at the cutter face. In addition, the operation during pipe-jacking processes, mud slurry and lubricant are injected into the cutter face and over-cutting area that is between the steel pipe and the soil respectively. Next, the slurry fills the voids out of cutter-face, so that the soil stabilizes due to the resulting mud slurry around the pipes. This type of pipe roof method will be available for underground developments in overcrowded urban areas in Japan.

Figure 9. Pipe roof method at tunnel entrance.

6. PIPE RENEWAL/ REHABILITATION

It is said that more than 390,000 km of sewer pipeline has been constructed since 1945 in Japan. A design life of sewer pipelines is regulated as 50 years. The length of sewer pipelines which should be inspected and, if necessary, repaired is increasing every year. Replacing old pipes with new ones creates problems, including traffic congestion caused by digging and the burden on the environment due to the disposal of surplus soil. This has been a concern for Japanese sewage engineers for over 15 years, and has been a driving force for the development of alternative repairing techniques for underground infrastructure. Recently, trenchless technology has overcome many of the problems of the old digging technology, bringing a host of benefits that make pipe replacement and repair much simpler.

The technology for renewing old or damaged pipelines consists of two methods: lining the inside of an existing pipe, and replacing an existing pipe with new pipe by breaking the existing pipe. Figure 10 shows the classification of pipe renewal methods.

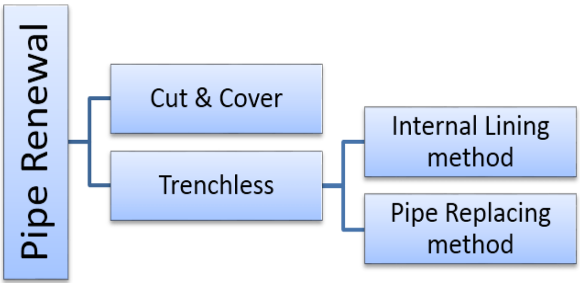
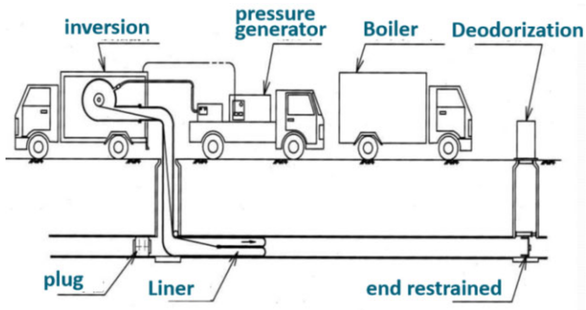


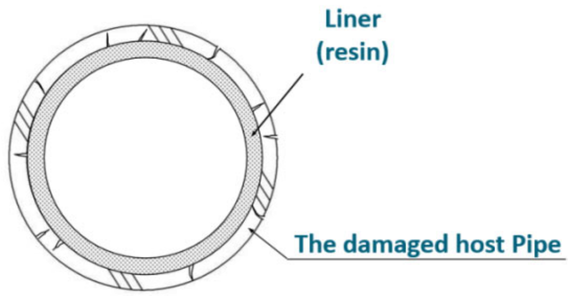
Figure 10. Classification of pipe renewal methods.

A. Internal Lining Method

As for the repairing of pipes, the inside pipe lining technique, such as cured in place pipe (CIPP) is mainly adopted. CIPP is a method of jointless, seamless, pipe-within-a-pipe with the capability to rehabilitate pipes. As a trenchless technology, CIPP does not require excavation to rehabilitate a pipeline that is either leaking or structurally unsound. In this method, a resin-saturated felt tube made of polyester, fibreglass cloth or a number of other materials suitable for resin impregnation, is inverted or pulled into a damaged pipe. The liner can be inverted using water or air pressure. The pressure required for inversion can be generated using pressure vessels. Hot water, UV light, ambient cured or steam is used to cure the resin and form a tight-fitting, jointless and corrosion-resistant replacement pipe. Figures 11 (a), (b) show the schematic diagram and cross-section view of CIPP. However, the cured in place pipe techniques could not be available for upsizing or size-for-size. Therefore, a replacement pipe jacking method aiming at the pipe line renewal has been developed in recent years.



(a) Schematic diagram



(b) Cross-Section view

Figure 11. Cured in place pipe (CIPP).

B. Pipe Replacing Method

There are several types of pipe replacing methods using pipe jacking systems. Among these methods, pipe bursting is a proven method of replacing and upsizing underground utilities safely and economically. By this method, damaged pipes are replaced with new pipes by breaking the existing pipes. Pipe replacement is performed by a pipe bursting machine which has one hydraulic jack. The hydraulic system is called 'Expandit'. Expandit can burst existing pipes by radial expansion, and new pipes could be installed on the same line. The installed pipe can be of the same size or larger size than the replaced pipe and a rectangular cross-section can be installed as the new pipe if desired. On the bursting process of old pipes, 'Expandit' is advanced by the pulling-chain to the arriving shaft, and at the same time, a new pipe is pushed in the cavity by the hydraulic jack being set in the starting shaft. The current Expandit can accommodate to the pipes which have the inner diameter of 200 to 600. Figure 12 is a picture of 'Expandit'. Figure 13 shows the relation between Expandit and pipes.

Figure 12. Rectangular pipe jacking machine.

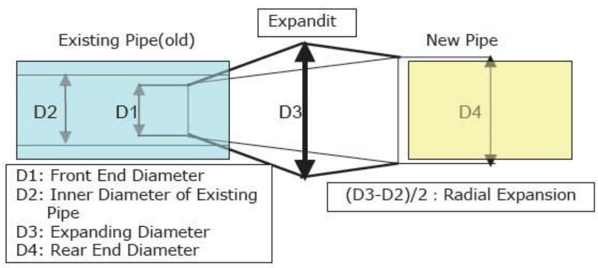


Figure 13. Construction of rectangular pipe jacking.

7. APPLICATION EXAMPLES INTO ASEAN COUNTRIES

In recent years, the demand for underground utilities in ASEAN countries is enormous due to rapid urbanization and economic growth. While countries have been developing rapidly, large-scale improvements of underground infrastructure such as water supply and sewage especially in large cities are needed more and more. However, the open cut method is difficult to be applied, since most of the ground area is occupied by structures in these areas.

From this point of view, application of the pipe jacking method on the construction of underground infrastructure is expected. Accordingly, Japanese companies have been trying to introduce their pipe jacking technology and its range of applications in ASEAN countries through a Japan government's official development assistance (ODA) program.

For example, Iseki Poly-Tech, Inc. has provided their micro tunneling project with long distance and curved jacking technology and has explored the appropriate business model for the construction work of PD PAL Jaya which is the public corporation managing the sewage works in Jakarta, Indonesia (Japan International Cooperation Agency and Iseki Poly-Tech Inc, 2015). The project is for sewer pipeline installation with pipe diameter 1,000 mm and 300 m long. Iseki dispatched an experienced engineer to this micro tunneling work and to carry out capacity development activities through on-the-job training to the operators of the local contractor. Through this project, it is expected that the Indonesian counterpart would be able to acknowledge the advantage of the long distance and curved jacking technology, which could minimize traffic congestion during construction when compared with the conventional method. Figure 14 shows the training photos in this project.

Figure 14. Pipe jacking construction project in Jakarta, Indonesia.

Another example is the water distribution pipeline project in Yangon, Myanmar. Most water pipes in Yangon City are old and leaky. In order to meet the future water demand, the Japan International Cooperation Agency (JICA) cooperated with the Yangon City Development Committee (YCDC) in a Grant Agreement, namely "Urgent Improvement of Water Supply System in Yangon City" (Japan International Cooperation Agency and TEC International Co., Ltd, 2013). The pipe jacking project is a part of this agreement, and the pipeline with 1,050 mm diameter is installed under Kabar Aye Pagoda road by a Japanese pipe jacking company. This company introduced Japanese trenchless technology for the first time in Myanmar to prevent the negative impact to the traffic during the construction. In addition, the company arranged for the local partners to study Japanese trenchless technologies and to develop their capacity. Figure 15 shows the construction photos in this project.

Figure 15. Pipe jacking project at Yangon, Myanmar.
Similar to these applications, many construction projects under the Japan ODA program are also being conducted in other ASEAN countries. In this way, Japan's advanced products and technologies are contributing to the construction of underground infrastructure, and helping to improve people's lives and promote economic development of developing countries.

8. ALTERNATIVE APPLICATION OF PIPE JACKING METHOD IN UNDERGROUND MINE PORTAL CONSTRUCTION UNDER WEAK GEOLOGICAL CONDITION

Nowadays, an increasing number of mines are being planned as well as extended with life spans in excess of 40 years. For such projects, it may be prudent to consider adopting design standards that are commensurate with civil engineering tunnels (Brox, 2013). When an underground mine is developed from an open cut highwall, it is essential to retain and maintain stability of the mine portal through the life of the underground mining. However, due to weak geological conditions, underground mine portal and roadway access failures can be found and fatalities could occur to mine workers. In addition, because of the instability, the mining operation may be disrupted and suffer reduced productivity while cost will be increasing. Therefore, considering that the higher safety due to less vibration, faster tunnel advance rate, and working environment is better for laborers compared to drill and blast, mine contractors are looking to change traditional mining industry and tunnel lining methodologies by using trenchless technology for a mine access.
Figure 16 shows a construction of underground coal mine portal with weak geological condition. The recoverable reserves of coal in this mine are 29.2 million tons. The company is being planned to produce 1 million tons per year of coal, and hence, it will take the production period about 30 years until the mine closure. In this case, pipe jacking technology can be applied for the construction of the mine portal for its safety and stability through the life of the mining. Through technology and innovation advancements, the opportunity to implement alternative excavation methods in the mining industry is becoming reality.

Figure 16. Underground mine portal construction at GDM coal mine, Indonesia.

9. CONCLUSION

This paper describes recent technologies of pipe-jacking for the construction method of underground infrastructure in Japan and its applicability to ASEAN countries. Trenchless technology is more and more widely used due to increasing amounts of investment in underground infrastructures. Recently, due to congested utilities in shallow underground areas, the development of effective, appropriately designed utilization of the deep strata is strongly encouraged in Japan. A lot of innovations in the pipe jacking methods have been made in order to overcome the various difficult conditions. In addition, University-industry-government cooperation has been growing at present, and it is expected that this cooperation will take further initiatives to contribute the pipe jacking technology to other countries from Japan.

10. ACKNOWLEDGMENT

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