Safety and vibration control of shield tunneling in gravel formation

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ABSTRACT

This article presents a case study of power transmission line constructed by shield tunneling method where the major soil stratum is gravel formation. The tunnels drilled through gravel stratum with maximum granule diameter of 65 cm with uniaxial compressive strength exceed 100 MPa and sandy shale stratum with a uniaxial compressive strength of approximately 7MPa. The designing and construction issues of this project include: 1. Overcoming gravel stratum, reducing construction vibration and promoting trenchless technique. 2. Monitoring construction vibration to avoid the adjacent Advanced-Tech plants from stop production. 3. Sustaining public safety and enviromental protection by innovative arriving method. The monitoring result and experience of this project could provide suggestions to the other similar shield tunneling cases.

Keywords: shield tunneling; gravel; vibration control

1 INTRODUCTION

This article presents a case study of power transmission line project constructed by shield tunneling method to fulfill the power supply and stability demand of Hsinchu Science Park (HSP). The HSP is located in the northern Taiwan and possesses annual value of production over 33 billion US dollars. Also, the IC foundry industry is top one in the world.

Refer to Fig.1, this project includes three sections of shield tunnels and five shafts. One tunnel section with 6.0m interior diameter was 1,522m long and the other two tunnel sections with 4.6m interior diameter were 814m and 800m long separately. The sizes of shafts ranged 12~16m and the excavation depths were 23~30m.

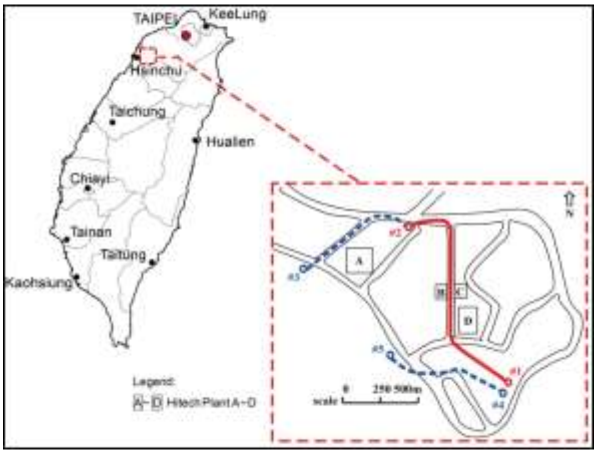


Fig. 1. General layout of project

2 GEOLOGICAL CONDITATION

According to Fig. 2 and 3, the tunnels drilled through sandy shale stratum and gravel stratum with maximum granule diameter of 65 cm. The uni-axial compressive strength of the two strata is approximately 7 MPa (sandy shale stratum)and 100 MPa (gravel stratum). The groundwater level is about 5~25m below the ground surface.

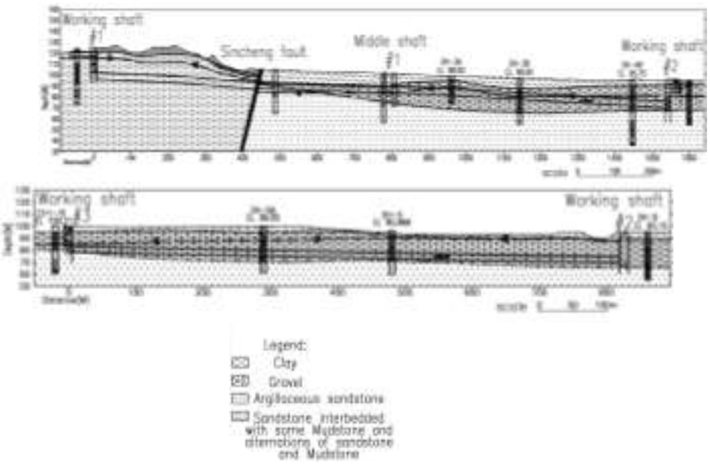


Fig. 2. Geological profile

Fig. 3. Gravel with maximum granule diameter of 65 cm

3 DESIGN AND CONSTRUCTION ISSUES

The tunneling rout drilled through gravel formation is close to a number of vibration-sensitive wafer fabs of HSP. There have been serious concerns about the vibration problem induced by the shield tunneling which could be hazardous to these high technology facilities. Thus the design and construction features of this project include:

1. Overcoming the gravel stratum and reducing construction vibration

(1) To overcome the gravel stratum, an open-type (spoke type) cutter face with an enlarged open ratio up to approximately 60% (generally 45%) and non-axial screw conveyor were adopted for the Earth Pressure Balance (EPB) shield machine as Fig. 4 shown. In general, screw conveyor can be divided as axial and non-axial type. A comparison between the two types is tabulated in Table 1. Since the maximum particle size of the gravel in the present project was 65 cm, the discharge of gravel should be considered to reduce the abrasion of the shield machine cutter and reduce vibrations. Therefore, the non-axial screw conveyor was employed. The shield machine face plate initially transports muck through openings in the cutter head and then through the soil chamber to the non-axial screw conveyor for removal. The screw conveyor was strengthened structurally to sustain the weight and vibration of muck during transportation.

Since the tunnel is drilled in highly permeable gravel stratum and the groundwater level is high, slurry material was pumped into the soil compartment to mix with the excavated muck not only to increase the fluidity but also to reduce the permeability. The density of the slurry as well as the opening of the conveyor should be adjusted to prevent groundwater flowing into the shield machine.

(2) The drilling principle was to transport all of excavated muck into the soil compartment including the whole gravels without crushing, thus no roller bits were installed for the cutting face as Fig. 4 shown. The advantage was to reduce the abrasion of cutters and the subsequent cost and risk to replace the cutters; it could also reduce subsequent vibration.

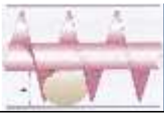
Based on the construction experiences, the typical rotational speed of cutter face was reduced to 0.87 rpm (ϕ 4.6m machine) and 0.75rpm (ϕ 6.0m machine) with overburden between 9 and 34 m not only to eliminate the drilling vibration but also maintain the drilling rate. As a result, the average daily drilling rate for the gravel stratum was around 5.4~6.8m which is relatively low compared to 6.0~10m for the soil stratum.

Internal Diameter =4.6m

Internal Diameter =6.0m

Fig. 4. Picture of Shield Machine.

Table 1. Comparisons of screw conveyor.

Type	Non-axial type	axial type
Schematic diagram		
Explanation	easy to move	easy to jam

2. Monitoring construction vibration to avoid the adjacent Advanced-Tech plants from stop production.

Before the shield machine drilled near Advanced-Tech plants, monitoring system comprising the sensors in the machine and on the ground was installed to measure the vibration data during construction.

The primary source of vibrations generated from the cutter plate located at the front of the machine. To monitor the vibration, it should not only measured the ground vibrations during excavation a portable vibration accelerator inside the shield machine was used to obtain the vibration measurements closest to the source on the partition between the cutter head and the soil compartment.

The measurement results are illustrated in Fig. 5. During excavation, the vibration level at the front of the machine was approximately 70 dB. Therefore, 70 dB was adopted as a daily management value for the excavation vibration generated during shield tunneling operation.

The subsequent monitoring results of vibration collected during the excavation stage and background vibration during machine downtime are illustrated in Figs. 6 and 7. The monitoring results suggested that the surface vibration at various frequencies generated during the execution of the project were far lower than the general surface vibrations generated by vehicle movement. In context of vibration velocity (frequency domain), no significant differences were observed between construction and background vibrations, and the vibration level on the ground was less than 40 dB. It implied that the excavation induced vibration was relatively small when compared with the background vibration. Therefore, it suggested that the construction vibration did not impact the yield performance of high technology plants. In addition, no plants were affected during tunneling, no yield problem caused by vibration was reported during the constrction of this project.

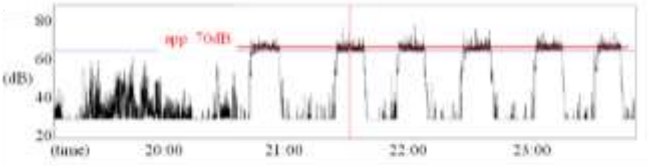


Fig. 5. The vibration monitoring results inside the shield machine.

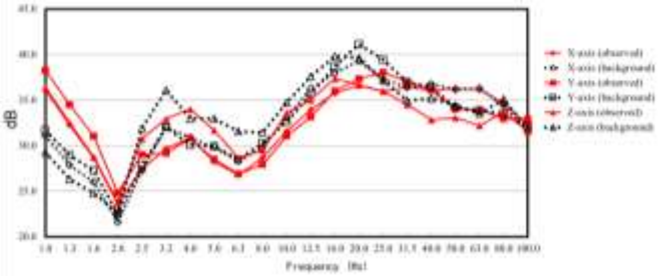


Fig. 6. The monitoring results at station #1 for background and observed during excavation.

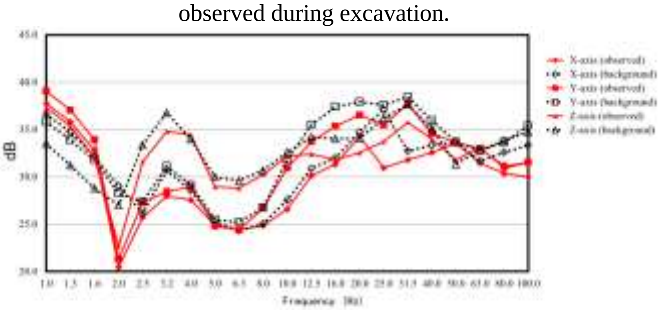


Fig. 7. The monitoring results at station #2 for background and observed during excavation.

3. Sustaining public safety and environmental protection by innovative arriving method.

Since the No.2 shaft with inner diameter 13m and depth 18m was located adjacent to the detention basin of HSP as show in Fig. 8, the ground water level was high and might result in safety problem during tunnel arrival. Except traditional ground improvement work was necessary, water was injected into the shaft to balance the inside and outside water pressure to secure arriving safety, avoid ground settlement and protect the detention basin from damage. The arriving process is shown in Fig.9 to Fig.18, the section and plan layout is shown in Fig. 19.

Fig. 8. Detention basin nearby working shaft #2

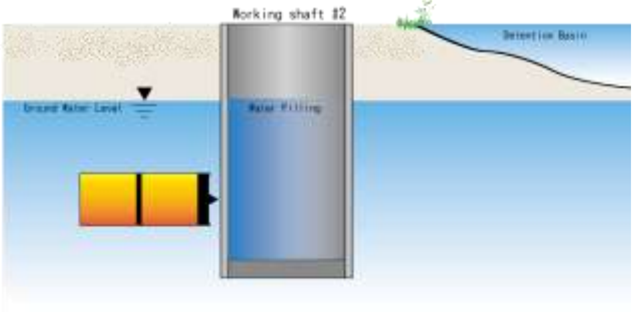


Fig. 9. The diagrammatic sketch of #2 shield machine reaching work shaft in water

Fig. 10. Demolish the wall of #2 shaft.

Fig. 11. Demolish work of #2 shaft.

Fig. 12. Completion of demolish work.

Fig. 13. Install watertight ring of tunnel face.

Fig. 14. Set up the arrival platform of shield machine.

Fig. 15. Water filling 9.6m deep.

Fig. 16. shield machine arrival.

Fig. 17. Dewater of #2 shaft.

Fig. 18. Completion of dewater work.

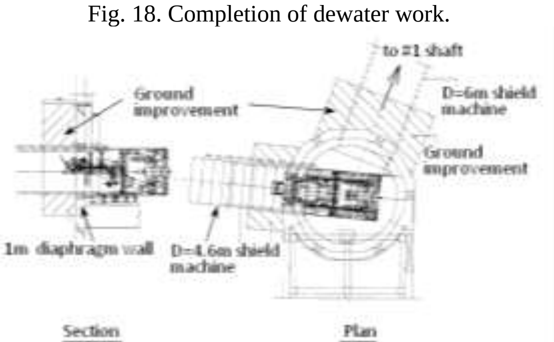


Fig. 19 Section and plan layout of #2 shaft and shield machine arriving work

3 CONCLUSION

The vibration value at the front of the shield machine during the excavation of gravel stratum was approximately 70 dB. This value can be used as the daily management value to monitor the excavation vibration generated from shield machine operations. In addition, the ground vibration level measured in the project was lower than background vibration. These results were possibly produced because the shield machine employed in the project comprised an open-type face plate with an enlarged open ratio. Thus uncrushed gravel was directed through the machine (the soil compartment) to the non-axial screw conveyor for removal.

In addition, traditional soil improvement combined with water injected into the shaft was used to secure arriving safety of shield machine. Based on the monitoring results during construction, the maximum ground surface settlement was 0.6 cm which is lower than the analysis results. The project was completed smoothly as design in 2014 and electrical power started to transmit in 2015. The innovative methods of this project can sustain public safety and environmental protection.

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