Planning and construction of the cross passage for Taipei MRT system

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ABSTRACT

When constructing a cross passage of a shield tunnel in the weak soil layer or under high ground water pressure, there will be a high risk of collapsing and piping during excavation. Therefore, it leads to the settlement around the site. If the work area is located on a silt-sand layer and close to houses, construction should pay more attention to the building protection. The construction of cross passage is always a high-risk work item in MRT projects. Due to the complicated stratum, limited geological survey, uneven quality of construction, and partially inspection for the whole project, the construction risk is still higher even the quality inspection of site improvement meets the specification requirements. So far, there are still many domestic and foreign cases about construction-related catastrophes.
This paper discusses the planning concept of cross passage based on Taipei MRT project. The cross passage shaft of Tender DG168 Songshan Line will be described to illustrate the construction methods, building monitoring, and protection measures. The setting of cross passage and construction safety can be rethought through the adjustment of overall disaster prevention concept or modification of construction method. The application of more reliable auxiliary method or the adoption of multiple protective measures will enhance the construction safety.

Keywords: MRT system, Shield tunnel, Cross passage.

1 INTRODUCTION

In order to solve the problems of high population, high building density, land expropriation difficulties, and to reduce the impact for environment in metropolitan area, we managed to make good use of underground space. Taking Taipei MRT as an example, the stations and route structures were built underground. Accordingly, the evacuation and escape plan owing to emergencies like fire should be taken into account. The MRT system has developed over 100 years, and the considerations for safety and evacuation of MRT system are mostly included in the design nowadays. According to data collecting and compaction, we can learn from the experiences of tunnel evacuation in the past. However, even with a comprehensive plan, there are still some unexpected accidents and incidents.

For the tunnel design of MRT in Taiwan, the most commonly used boring machine is single-tube boring machine, by which to form two unconnected tunnels. For the purpose of effectively evacuating passengers in the tunnel when emergency happens, designers in general would adopt the regulation made by National Fire Protection Association (NFPA). In the regulation, designers should set cross passages between two main tunnels with an appropriate distance. The cross passages can not only be used as escape walkway but also be maintenance passages. However, the complex stratum and unexpected incidents make it much harder to construct a cross passage. It is a high risk procedure of tunneling, and catastrophe happened in the middle of constructions are not rare at home and abroad.

2 PLANNING OF CROSS PASSAGES

2.1 Constructing method

In general, digging by man is mainly used to construct cross passages, and it is similar to the New Austrian Tunneling method (NATM method) for mountain tunnels. The procedures are excavating in stages, and strengthen the excavation face by a flexible combination of rock bolts, wire mesh and shotcrete. Finally, the permanent support is typically a cast-in-place concrete lining placed over a waterproofing membrane.

Before constructing a cross passage, usually it would go along with auxiliary methods such as dewatering, grouting, or freezing method. After that, the quality and waterproofing ability of the grout body is tested, and additional chemical grouting is applied if necessary.

2.2 Auxiliary method

It can easily cause catastrophes while excavating. Hence, the auxiliary method like ground improvement or water blocking procedure must be made. The currently used auxiliary method for cross passages in Taiwan is mainly jet grouting, and a few freezing method. The compressed air tunneling was once applied to constructions, but it was called off owing to the labor safety issues. Table 1. shows the comparisons between auxiliary methods.

Due to the soft stratum and high ground water pressure, it would cause serious leakage of water and sand if the construction was careless or the grout body had poor quality. The grouting method has been used for decades in Taiwan, and the applying experience is abundant. Nevertheless, the underground situation is unknown. Especially the underground obstacles would affect the formation and uniformity of the grouting area.

In addition, we can only confirm the grout body condition by sampling, and the sample testing results might be biased and limited. As for the water testing procedure, because the grout body has deformed into a new type of soil, the gap between the original soil and the grout body would be the main route for water leakage. Thus, it would be difficult to properly evaluate the coefficient of permeability. Moreover, the limited numbers of water testing holes can't make sure whether there are any defects or cracks.

The ground improvement is a necessary work for cross passage excavation, but the restricted grouting quality and incomprehensive water testing make it hard to confirm the grout effectiveness. Therefore, the excavation in weak stratum is still a high risk construction, even with the qualified grouting samples.

Table 1. Comparisons between auxiliary methods.

Auxiliary method	Applicable conditions	Procedure	Effectiveness
Freezing method	Adapt to all kinds of stratum, especially for the region of high water pressure, high risk, deep excavation depth, and ineffective grouting.	Install freezing tubes into the stratum, and take away the heat by cycling the freezing fluid in tubes.	Best
Grouting method	Adapt to sandy soil, which can raise the strength and reduce the permeability. Owing to the low permeability of clay soil, it mainly raises the soil strength.	Before the excavation, proceed the grouting injection and water test. If the grout body is not qualified, the chemical grouting is applied to support.	Good
Compressed air tunneling	Adapt to low permeability soil, and it generally incorporates with grouting method to reduce water leakage from cutting face.	With the compressed air, the high water pressure would be confined outside the cutting face, and it can also dehydrate the stratum to strengthen the soil strength.	Better

2.3 Setting consideration

According to the regulation of NFPA 130 (2003), "Within enclosed trainways, the maximum distance between exits shall not exceed 762 m (2500 ft).", "Cross passages shall not be farther than 244 m (800 ft).", and "Cross passages shall not be farther than 244 m (800 ft) from the station or portal of the enclosed trainways.". Taipei MRT then adopted the regulation from "Design manual for civil facility requirement and planning", which mentions that cross passages shall not be farther than 300 m (It can be adjusted based on the in situ conditions after approval.). Therefore, unless the passage number is reduced by special considerations, the Taiwan MRT system need to set a cross passage in a certain distance between two single-tube tunnels, in order to provide walkway for evacuate situations.

The main purpose for cross passage design is to adapt for passengers to evacuate, and whether to set a cross passage or not is in accordance with the different disaster prevention concept and risk management of each country. In Taiwan, the MRT Operating Standard requires that if an emergency occurs, the train in the tunnel shall deliver passengers to adjacent station. But it also mention that if the train is not capable of delivering passengers, passengers will need to evacuate from the tunnel; thus, a cross passage is planned to set.

Other countries such as Japan and United Kingdom, they assume that the train can transport passengers to nearby station, so there is no such cross passage concept in their tunneling design.

According to the tunnel alignments, there are two types of cross passages. One is for parallel pattern tunnels (see Fig. 1.(a)), the other is for stacked tunnels (see Fig. 1.(b)), and the latter usually comes along with a vertical working shaft. Moreover, the vertical stacked cross passage is much more complex than the horizontal one, with more excavation quantities, risks, and costs.

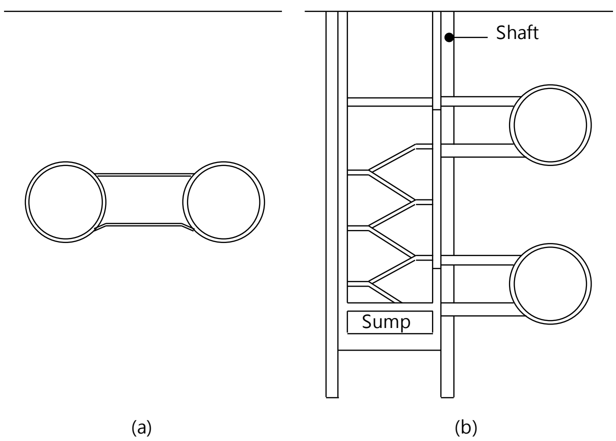

Fig. 1. (a) Horizontal cross passage (b)Vertiacal cross passage

3 CASE STUDY

This case contains a pair of stacked tunnels and a vertical cross passage with an excavation depth of 30 m of Taipei MRT Songshan Line Tender DG168. The site is at the intersection of Nanjing East Rd. and Keelung Rd., and is mainly covered with clay.

3.1 Ground improvement

There were two stages of ground improvement. The first stage was a series of vertical grouting before boring machine passing through, and the second stage applied horizontal grouting from the shaft before excavating the cross passage.

In the first grouting stage, the maximum grouting depth was 35 m, and in order to avoid existing culverts, the region below them need to be grouted with an angle; therefore, some soil might not be fully improved (see Fig. 2.). With the purposes of not damaging tunnel linings and the former stage grout body, the low pressure horizontal grouting (double-packer grouting) was applied in the second grouting stage. Finally, the water test was provided to ensure that the follow-up procedures such as excavation and steel segments removal would be secured.

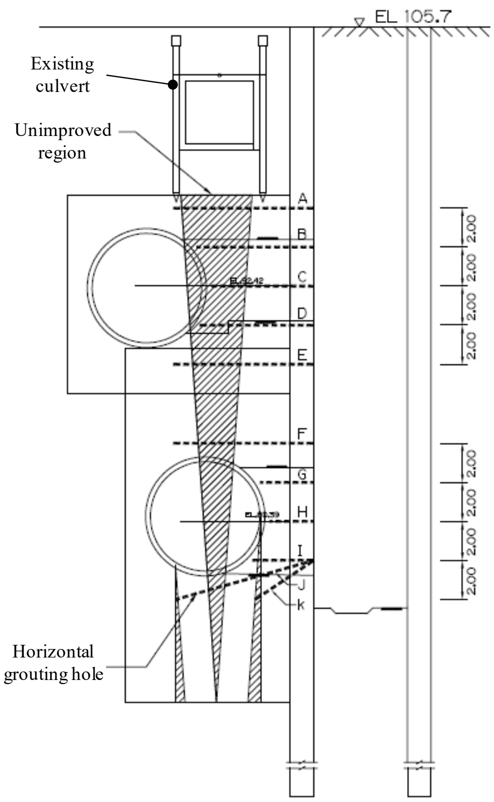

Fig. 2. The unimproved region due to the existing culverts.

3.2 Cross passage excavation

3.2.1 Monitor instrument layout

To realize the situation of adjacent buildings and ground movement, there were instruments set in the tunnel, on the ground and buildings while constructing the cross passage. In this case, the influence circle (radius = 30 m) contained a building only, and four buildings were near by the area. The contractor installed Tilt meters (TI) and Settlement point on buildings (SB) to monitor the movements. In the tunnel, the Convergence Points (CP) were arranged to inspect the segment deformations. Settlement Reference Points (SM) were installed along the tunnel alignments. Table 2. refers to the frequency and control values of monitoring.

Table 2. The frequency and control values of monitoring.

Instruments	Alarm value	Action value	Frequency
Settlement point on building or foundation (SB)	According to each type of buildings.		During passage excavation： 1 time/ 1day During structural construction： 1 time/ 3 days
Tilt meter (TI)	According to each type of buildings.		
Settlement reference point for concrete/asphaltic pavement (SM)	36 mm	45 mm	
Surface settlement indicator (SSI)	36 mm	45 mm	
Convergence Point (CP)	12 mm	18 mm	

3.2.2 Excavation

To make sure that the tunnel lining would be secured while excavating, there were five steel rings on each side of cross passage (see Fig. 3.) to keep lining round. On the other hand, in order to confine the disaster to minimum if a catastrophe happens, a safety gate would be set before excavating to reduce the damage on the shaft side (see Fig. 4.).

Fig. 3. Steel rings of protecting tunnel segments.

Fig. 4. The safety gate at the shaft side.

Besides, a part of the grouted region was injected with low pressure, so the strength was weak. To increase the self-stand ability of soil, the contractor managed to drilled holes at outer region of cross passage to install steel pipes and inject the Polyurethane resin, which could effectively prevent the collapse of excavating face. After that, the excavation began with man digging and small-sized machine. There were two phases, the first was upper passage excavation, and followed by a series of rock bolts, wire mesh and shotcrete. The second phase applied the same procedure at the lower part of the passage (see Fig. 5.).

Fig. 5. Man excavation.

3.2.3 Structural construction

After digging through the cross passage, the steel segments on the arriving side (see Fig. 6.) and the safety gate on the launching side were removed. The next step was placing a waterproofing membrane, and finally, pouring concrete in an order of lower plate, wall, passage crown, and side wall.

Fig. 6. The steel segments removal.

4 CONCLUSION

A cross passage construction is basically consisting of ground improvements and excavations. Since the passage is digging by man, there would be no additional protection from hoods like boring machine. Furthermore, the site is under high water pressure. The only precaution method is to apply ground improvement, but it is limited by complex stratum and uneven grouting quality. Thus, the whole construction is classified as a high-risk procedure.

With abundant domestic experiences in constructing process, the multiple precaution concepts are adopted. For instance, a qualified ground improvement collocates with the rigorous water test and the chemical grouting. Other auxiliary method such as freezing method can also lower the risk effectively. The safety gate and steel segments, on the other hand, play important roles of minimizing the emergence damages, which can reduce the repairing costs and time.

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