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A Review of Metro Tunnel Construction Methods

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Abstract. The construction of metro tunnel is limited by geological conditions. Therefore, it is important to choose an appropriate construction method that suits the local conditions. This paper summarizes three major methods of metro tunnel construction, including their principles, processes, applicable conditions, strengths, weaknesses, and latest developments. This paper aims to provide reference to subway station constructions and related scientific research.

1. Introduction

Metro is one of the main public transports carrying most of commuters in major cities because of its advantages like efficiency, safety, convenience and so on. Major cities are continuously expanding their metro system to satisfy the increasing demands of commuters, therefore more and more metros are being constructed.

It is important to select the suitable method of construction for each project. The selection should be made based on the trait of each project, and to satisfy both the function of the metro engineering itself and the demand of exploiting and utilizing the useful space of both above and under the ground. At the same time, the negative effects to surroundings brought by the metro construction should be minimized. Selection for construction method has huge effect on the line embedment, the structural form of metro station and the construction period will directly influence the cost of the project and the benefits in society, economy, and environmental protection further.

There are three main construction methods that are widely used in the metro construction both at home and abroad, namely the Cut and Cover Method, New Austrian Tunnelling Method, Shield Method. The combination and innovation methods of metro construction are mainly based on the above methods. In practice, it is important to identify the character and application condition of each method to select the most suitable construction method for the project. In this paper, a review of the three methods is presented to help engineers gain a further understanding to these methods.

2. Cut and Cover Method

2.1 The introduction of Cut and Cover Method

Cut and cover method is an underground construction method which starts from the ground. The excavation is up-to-down from the basement to the designed elevation, then the major structure of the tunnel is constructed from the bottom to top. Finally, the construction was ended with backfilling the foundation pit or restoring the ground. The cut and cover method can be classified to two modalities according to the excavation method: unsupported slope excavation and supported foundation pit excavation. The unsupported slope excavation occupies a large area. While in the case of limited site conditions, measures to reinforce the side wall of foundation pit are needed in order to guarantee the safety of the side walls and surrounding buildings, which is supported foundation pit excavation.



2.2 The advantages and disadvantages of the Cut and Cover Method and its applicable conditions

In general, the advantages of cut and cover method lie in its simple and economical technology and a well-stressed main body. It is the primary choice of underground construction when there is no limitation on ground traffic and environment, because the subsection and simultaneous construction can be achieved when needed. However, it has obvious disadvantages: 1) it will block the traffic for a long time; 2) the noise and vibration have great impact on urban traffic and residents' lives; 3) it is difficult to control the land subsidence caused by the excavation of deep foundation pit in saturated soft soil stratum.

The application of cut and cover method is related to many factors, including the surrounding conditions, engineering geology, hydrologic geology, the depth of works and its technical and economical indications. In the metro station construction, the cut and cover method is mainly used in the following two conditions: 1) Shallow buried underground engineering with the thickness of the covering soil of these projects being about 5-10 meters; and 2) Underground engineering with large plane size. For such projects, partial excavation or trench excavation is usually adopted in cut and cover method.

2.3 The technical development of cut and cover method

With the progress of scientific technology and the technical level of construction, the cut and cover method has been greatly improved in the following aspects [1]:

1) Exterior-protected structures. The types of support for selection include steel sheet piles, board piles, reinforced concrete prefabricated sheet pile, column type board pile, digging pile, cement mixing pile, soil anchor, soil nail and underground continuous wall.

2) Supporting system. There are two main categories of support structures, namely internal support and external pull anchor, and many new types could be used for each category. For example, internal support now includes steel braces, reinforced concrete braces, purlin and column braces.

3) Groundwater control technology. When the cut and cover method is applied in areas with high groundwater level, drainage methods include clear drainage, blind ditch method and artificial well-point dewatering.

4) Technology of cover excavation. It is excavated from the ground to a certain depth, and then closes the top part and the rest of the lower part is constructed under the closed roof. The cover excavation method is adopted to overcome the shortage of affecting the ground traffic in Cut and Cover Method.

3. New Austrian Tunneling Method

3.1 The introduction of New Austrian Tunneling Method

The New Austrian Tunneling Method (NATM) is the application of rock mechanics theory and based on maintaining and utilizing the self-bearing capacity of the surrounding rock. The key principle of NATM is using the surrounding rock as a part of the support system [2].

The construction process of new Austrian method is: 1) Line positioning; 2) drilling, loading and blasting; 3) dust removal by ventilation; 4) anchor and steel arch support and bar-mat reinforcement; 5) shotcreting to form the preliminary bracing; 6) building the concrete as the secondary lining. Rabcewicz [2] emphasized three key points of NATM: the first is the application of a thin-sprayed concrete lining; the second is the closure of the ring as soon as possible and the third one is systematic deformation measurement.

3.2 The advantages and disadvantages of NATM and its applicable conditions

The advantage of new Austrian method is that it maintains the strength of the original surrounding rock to the largest extent. The timely support and close contact with the rock surface also helps the integration of the surrounding rock and lining, which omits the supporting component in the traditional construction. By using thin layer support, the engineering quantity of excavation and

masonry can be reduced. Besides, the design and construction are much more reasonable with lower cost. NATM can show its superiority in weak surrounding rock, poor geology conditions and shallow tunnels. While the disadvantage of new Austrian method is that it asks for a higher requirement of technology and a number of collapses and failures of NATM tunnels occurred in the history [3].

Since NATM need to make use of the strength of surrounding rock mass, there are some requirements for geological conditions. It is mainly applicable to some stable and relatively hard rock masses. In contrast, the applicable of NATM should be assessed carefully for poor geological conditions, such as the existence of water burst and the heaving sand, or when the rock is extremely broken and the excavation surface cannot be completely self-stabilized

3.3 The development of NATM

The development of NATM is related closely with the development of the material, approach and equipment for shotcrete and rock bolt support. In the field of construction equipment, it is promising to develop a shotcrete system with high initial and long-term strength, low rebound, low dust and high productivity, which is matched with the high-efficiency dust collector, the automatic injection gear and the short-cycle material supply system.

4. Shield Method

4.1 The introduction of Shield Method

Till now, shield method is the most widely used method in subway construction. Tunnel boring machines (TBM) are used in modern shield tunneling. A TBM consists of a shield and trailing support mechanisms. The soil is excavated by the cutting wheel at the front end of the shield and being removed through the machinery as slurry or left as-is depending on the type of the TBM. A set of hydraulic jacks are used to push the TBM forward. Then, the erector is used to pick up precast concrete segments and locate them in the designed position to form a new tunnel ring.

The main procedures of the shield method are as follows: 1) excavating foundation pit or building vertical shaft at the beginning and end of the tunnel; 2) excavating the soil layer; 3) advancing the TBM and deviation correction; 4) lining assembling; 5) lining pressing.

TBM is consisted of shield shell (shield), digging mechanism, propulsion mechanism, dumping mechanism, lining mechanism and auxiliary mechanism.

4.2 The features and application of Shield Method

The features of shield method are: 1) there are little impact on the ground traffic and surrounding environment; 2) the shield machine is designed, manufactured or reformed according to the characteristics of the tunnel and geological conditions; 3) there are high requirements for construction precision; 4) the construction cannot be retreated [4].

The advantages of shield method are as follows: 1) Most of the operations are carried out underground, which have no effect on the ground traffic or navigation and little effect of noise and vibration on the nearby residents; 2) the main process of the construction, the shield propulsion, earth cutting and lining assembling, are circulated and the construction is easy to manage; 3) the construction is not affected by climatic conditions; 4) a higher technology superiority when constructing a tunnel with deep depth and long distance at a place of poor soil quality and high water level [5].

However, there are also some problems of the shield method, such as the poor adaptability in the section with variable section size, the high costs on the shield machine, uneconomical choice for short construction section and a bad working environment for workers.

The shield method can cross stratum with complex engineering and hydrogeological characteristics and has a wide application scope. It is suitable for the construction of different structures ranging from the subway tunnel to the underwater tunnel and the buried station because of

the different diameter of the shield and different shapes such as the single circle shield, double O-tube shield and multi-circular face shield.

4.3 The development of construction method of shield tunnel

With the rapid development of subway in China, the shield method will be widely applied and progressed due to its advantages on safety, environmental protection and construction period [4]. The development of shield method followed by the development of modern science and technology will focus on the diversification of the construction section, the technology of lining assembly and the automation of the shield construction.

1) Special cross-section shield [6]. In order to adapt to different geological conditions and some special projects, more and more shield machine structures are appearing, such as multi-circular shield, elliptical shield, rectangular shield, deformation section shield, H&V shield, mechanized shield, etc.

2) The development of new construction technology, which includes the import and export technology, the ground docking technology et al, so as to meet the special construction requirements.

3) The automation of the piece assembly and the development of new lining technology. The technologies include pressure-grouting concrete lining, pipe joint technology, pipe joint seepage control technology and the manufacturing of pipe with high strength and durability et al.

4) Automatic excavation. With the development of computer technology, the shield will have the function of data collection and automatic direction control.

5. Conclusion

The cut and cover method is still the primary choice in metro construction, but exploiting maintenance technology of deep foundation pit and as well as slope support is the prerequisite of a much higher efficient use in the further.

As for NATM, the strong ability of adapting to complex geological conditions is a big advantage of it. However, utilizing new Austrian tunneling method is more complex because this method requires more than the use of sprayed concrete. It is the understanding of the theoretical basis of the NATM that requires most.

High cost as shield method brings, its control in bottom settlement and the fast and safe construction guarantees a continuous development for it. The combination of shallow mining method and shield method can make full use of its advantages by utilizing the interval shield machine to continuously complete the interval tunnel and the station traffic, which improves the advance distance of the shield machine, and shortens the construction period and reduces the amount of civil works.

In general, different geological conditions and construction environments requires different methods for different project. More efficiently and economically construction will be achieved if a reasonable construction scheme is properly selected and well designed.

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