Research on Excavation and Support Design of Inclined Shaft TBM for Pumped Storage Power Station

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Abstract. This paper firstly analyzes the installed capacity of pumped storage power station, power generation head, Angle of inclined shaft, design requirements of regulation guarantee, head loss, etc. The preliminary design of inclined shaft is studied. Then, the comparison of 3 schemes of diversion inclined shaft TBM construction is carried out. Comprehensive consideration is given to the factors such as structural layout, water head loss, guarantee safety in complex adjustment state, construction difficulty and safety risk, etc. Comprehensive analysis shows that it is more feasible to adjust the upper inclined shaft, middle horizontal hole and lower inclined shaft into a primary inclined shaft, and adopt the TBM with diameter Φ7.2m section to carry out diversion inclined shaft construction. The design scheme can provide technical reference for the design and construction of similar projects in China.

Keywords: inclined shaft TBM construction scheme optimization support design

1 Introduction

TBM (Tunnel Boring Machine, full section tunnel boring machine) construction technology, as the most advanced tunnel construction technology, has been widely used in the construction of large long tunnels in railway, water conservancy and other industries, and has shown outstanding advantages[1-2] in quality, schedule, safety, environmental protection and civilized construction.

At present, there is no precedent for the application and construction of TBM for large slope inclined Wells in China, and few TBM applications are implemented in pumped storage projects. The construction design of inclined shaft has always been the key work[3] of pumped storage power station. "Reverse drilling method" and "climbing tank method" are usually used in the construction and excavation of inclined shaft in domestic pumped storage power station. These methods are accompanied by the shortcomings[4-5] of long time limit, high risk and large labor input. TBM construction technology is rarely used in domestic pumped storage power station, especially in inclined shaft construction. At present, the research on the TBM construction of diversion inclined shaft mainly focuses on the selection[6-8] of TBM equipment. However,

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there are few researches on TBM construction scheme. Therefore, the research of inclined shaft TBM construction is of great significance[9] for the design and construction of pumped storage power station and the development of TBM technology in our country.

Construction of pumped storage projects is currently at its peak, and the construction period of pumped storage projects is becoming shorter and shorter. More and more new construction methods are being introduced into the construction of pumped storage projects, and the construction of the water intake system of pumped storage projects has become one of the main factors restricting the construction period. If TBM is used in the construction of inclined shaft, it can not only significantly improve the construction efficiency, shorten the construction time of water diversion system, reduce the construction safety risk, and protect the safety of operators; At the same time, the improvement of construction equipment and technology will also feed the design of pumped storage power station. It can be considered to combine multiple short inclined Wells into one long inclined Wells to reduce the hydraulic loss of the diversion system and optimize the design of the diversion system. The inclined tunnel TBM, as a cutting-edge method for constructing inclined tunnels, has the characteristics of high safety performance, high construction efficiency, and fast excavation speed, which reduces the difficulty and risk of inclined tunnel construction and improves construction safety. It is also beneficial for optimizing the layout of the water system in pumped storage projects. However, due to the lack of complete mastery of the design and construction of inclined tunnel TBMs in China and the lack of complete maturity[1] of the TBM equipment technology, the construction of inclined tunnel TBMs has not been widely promoted in China.

In order to speed up the construction of pumped storage power station, improve the mechanization and green level, this paper takes a domestic pumped storage power station as an example, put forward the TBM construction technology, the optimal design method; The design scheme of the III type surrounding rock TBM construction support is put forward, which provides technical guidance for the later project using TBM construction technology.

2 Preliminary Design Scheme of Water Diversion Inclined Shaft TBM

At first, the diversion system of a domestic pumped storage power station was excavated by conventional methods. Due to the breakthrough of domestic technology, the diversion system applied TBM construction, and the diversion system needed to be improved. Fig. 1 is the original design of the water diversion system.

2.1 Design Idea of Diversion Inclined Shaft TBM

According to the TBM construction requirements of the water diversion system, three TBM construction design schemes are preliminarily drawn up. The three design schemes are:

Scheme 1: the upper inclined shaft, the middle horizontal hole and the lower inclined shaft are adjusted to the first level inclined shaft; The construction of the whole inclined shaft is TBM, and the profile is shown in Figure 2.

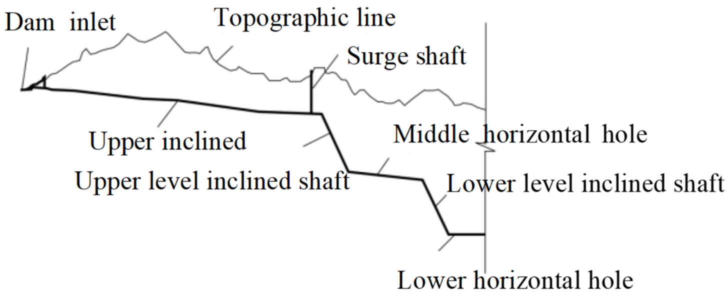

Fig. 1. Schematic diagram of the original design of the water transmission and power generation system

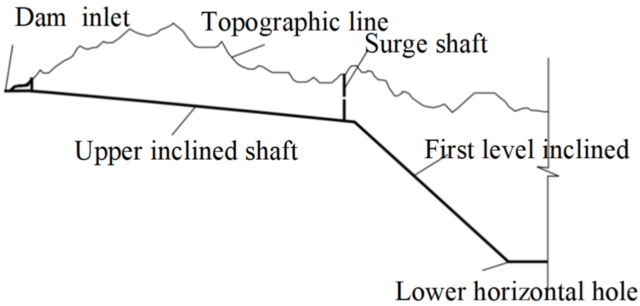

Fig. 2. Section diagram of Scheme 1 water transmission and power generation system

Scheme 2: The upper horizontal hole, upper inclined hole, middle horizontal hole and lower inclined hole are adjusted to the first level inclined hole; The concrete lining section of inclined shaft adopts TBM construction, and the profile is shown in Figure 3.

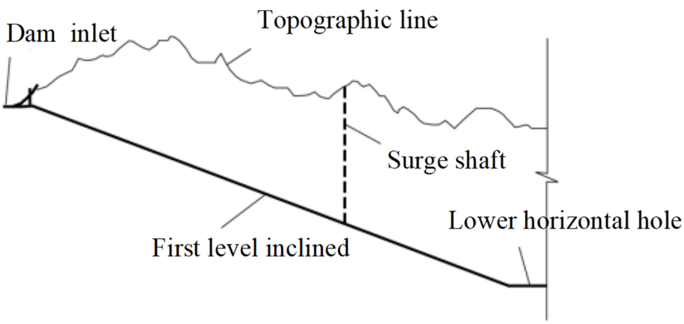

Fig. 3. Section diagram of Scheme 2 water transmission and power generation system

Scheme 3: the horizontal hole and the upper inclined shaft of the diversion water are adjusted to the first inclined shaft; The concrete lining section of the upper inclined shaft adopts TBM construction, and the profile is shown in Figure 4.

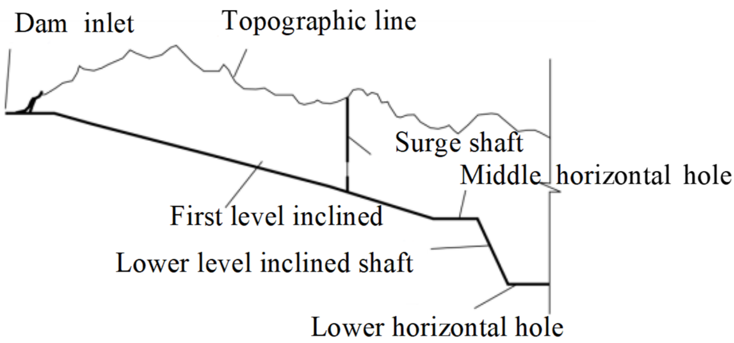

Fig. 4. Section diagram of Scheme 3 water transmission and power generation system

3 Inclined Well TBM Design Scheme Comparison and Selection Method

3.1 Structural Layout Analysis

The main project characteristic parameters of three schemes 1# diversion tunnels are shown in Table 1.

Table 1. Structural layout parameters of the three schemes

Project characteristics	Original design proposal	Scheme 1	Option 2	Option 3
Length of main drainage hole (m)	2940	2829	2739	2753
Pressure aqueduct length/diameter (m)	1660/6.5	1660/6.5	1718/6.5	1697/6.5
laximum static head of pressure catchme (m)	166	166	488	358
Pressure pipe Length/diameter (m)	1280 (6.5/5.6)	1169 (6.5/5.8/5.6)	1021 (6.5/5.6)	1056 (6.5/5.6)
Surge chamber shaft height (m)	196	196	518	387
Inclined shaft length (m)	267/273	928.255	2434.761	2004.203
Inclined well Angle (°)	60	36.236	16.31	11.604

As can be seen from the table, the length of the main diversion hole of the three TBM construction schemes is 111m, 201m and 187m shorter than the original design scheme, respectively. The length of the pressure aqueduct in scheme 1 is the same as that in the original scheme, while the length of the pressure aqueduct in scheme 2 and

Scheme 3 is increased by 58m and 37m respectively. The maximum hydrostatic pressure of the pressure catchment channel of scheme 1 is also the same as that of the original design scheme, while the maximum hydrostatic pressure of the pressure catchment channel of Scheme 2 and Scheme 3 is increased by 322m and 192m respectively compared with the original scheme. Under the same conditions, the leakage water of the concrete lining section of Scheme 2 and Scheme 3 is more than that of Scheme 1, and the high pressure tunnel section of Scheme 2 and Scheme 3 is longer. The stress situation of the lining structure of the bad geological section is complicated, and the treatment difficulty will be relatively large.

The length of the pressure pipeline behind the water diversion surge chamber of the three TBM construction schemes is 111m, 259m and 224m shorter than that of the original design scheme. The shaft height of the surge chamber in scheme 1 is the same as that of the original design scheme, while the shaft height of the surge chamber in scheme 2 and Scheme 3 is increased by 322m and 191m respectively compared with the original design scheme. Moreover, the connecting pipe lengths of the surge chamber in both schemes are 451m and 320m respectively, and the shaft heights of the surge chamber are both over 400m, which is difficult to construct. The height of the shaft of the surge chamber in scheme 2 exceeds 500m, and it is necessary to add construction branch holes in the middle to meet the construction requirements. From the point of view of structural layout, scheme 1 is the best.

3.2 Head Loss Analysis

Technical results of head loss in water delivery system are shown in table 2.

Table 2. Comparison of calculation results of water head loss of water transmission system

Project Characteristics	Original design proposal	Scheme 1	Option 2	Option 3
Head loss (m)	14.569	14.928	13.969	14.313

It can be seen that scheme 2 has the shortest water diversion route and the least head loss. The head loss of the original bidding design scheme, scheme 1 and scheme 3 is basically the same. Considering that the cost of TBM construction increases more than that of traditional drilling and blasting method, the economic hole diameter of TBM construction should be relatively small, and the head loss can be appropriately increased, and the head loss of scheme 1 water transmission system is appropriate.

3.3 Design and Analysis of Guarantee Safety in Complex Adjustment State

The comparison of the calculation results of the head loss of the three TBM design schemes is shown in Table 3

Table 3. Summary of calculation results of head loss of water transmission system

Project Characteristics	Original design proposal	Scheme 1	Option 2	Option 3
Pressure Pipe Flow Inertia (m)	1.395/1.359	1.357/1.37	1.223/1.191	1.306/1.277
Length of surge chamber connection pipe (m)	116	116	451	320
Maximum dynamic water pressure value a volute end (m)	942.62	938.78	943.59	948.62
Minimum draft pipe pressure value (m)	62.53	61.56	61.11	61.87
Maximum surge of surge chamber (m)	1239.42	1239.88	1239.35	1239.76
Minimum surge in pilot surge chamber (m	1208.54	1208.92	1208.40	1208.55
Maximum surge in tailwater surge chamber (m)	611.49	611.48	611.47	611.49
Minimum surge in Tailwater surge chamber (m)	589.98	590.02	590.19	589.91

It can be seen that considering the influence of the length of the connecting pipe on the guarantee safety in complex adjustment state design, the maximum dynamic water pressure value at the end of the volute in scheme 1 is the minimum. Scheme 2 and scheme 3 pressure pipe flow inertia time constant is smaller than the original design scheme, but because the surge chamber connection length is the longest, the maximum pressure value at the end of the volute and the minimum pressure value of the draft pipe are worse than the original bidding design scheme. From the Angle of regulation guarantee design, scheme 1 is the best.

3.4 Construction Technology and Period Analysis

The inclined shaft lengths of the three TBM construction schemes are 928.255m, 2434.761m and 2004.203m respectively, the slopes are 36.236°, 16.31° and 11.604° respectively, and the excavated section dimensions are 7.2m, 7.8m and 7.8m respectively. Scheme 1 adopts self-weight slagging (this project mainly consists of bedrock fissure water, according to the seepage water quantity of the flat hole of the workshop exploration and the excavation disclosure of the tunnel of the preparation for the standard project, and referring to the geological professional opinions, the initial estimated seepage water of the diversion incline is 150m^3/d, the slag material has a small water content after the excavation of TBM, and the inclination of the diversion incline is greater than 30°, which basically meets the self-weight slagging). Scheme 2 and scheme 3 need to use continuous belt conveyor to excavate slag from top to bottom. TBM equipment cost of the three schemes is basically the same. Considering the continuous construction of TBM equipment and cost allocation, Scheme 2 and scheme 3 are better, but the TBM construction cost will increase a lot.

From the point of view of the excavation period, the total excavation period of scheme 1 using TBM construction is 19 months, which is 5 months shorter than drilling and blasting method. In scheme 2 and scheme 3, the total excavation period of TBM construction is 35 months and 31 months respectively, which is 10.5 months and 6.5 months longer than that of drilling and blasting method. Scheme 1 has the shortest excavation period.

From the perspective of the difficulty of lining construction, considering that the installation and concrete pouring of ultra-long inclined shaft in scheme 2 and scheme 3 are more difficult, under the same layout scheme, scheme 2 and scheme 3 will affect the power generation period.

From the perspective of safety risk sources, the major safety risk sources of the original design scheme are mainly the construction of upper and lower inclined shaft, scheme 1 is mainly TBM construction, scheme 2 is mainly TBM construction inclined shaft and ultra-long shaft construction, scheme 3 is mainly TBM construction, long shaft construction and lower inclined shaft construction. The safety risk sources of scheme 1 are relatively few.

3.5 Scheme Determination

Considering the structural layout, water head loss, guarantee safety in complex adjustment state, construction difficulty and safety risk and other factors, the upper inclined shaft, middle horizontal hole and lower inclined shaft are adjusted to the first inclined shaft. The TBM with diameter of Φ7.2m is more feasible for the construction of diversion inclined shaft in scheme 1.

4 Conclusion

This paper discusses the application of TBM in the construction of inclined tunnels in pumped storage projects, as well as related design schemes and technical challenges. TBM technology is widely used in tunnels and underground engineering due to its advantages in quality, schedule, safety, and environmental protection.

This paper presents three TBM construction design schemes for the water intake inclined shaft of a pumped-storage power station, and compares their structural layout, water head loss, guarantee safety in complex adjustment state, construction difficulty, and safety risks. Through the comparative analysis, Scheme 1 is the most optimal in terms of structural layout, as its water intake main tunnel length is shorter than the original design scheme, and the length of the pressure water supply tunnel and the maximum static water pressure are the same as the original design scheme. Scheme 2 is the most optimal in terms of water head loss, as its water intake route is the shortest. From the perspective of regulation guarantee safety in complex adjustment state, Scheme 1 is the most optimal, as its snail shell end has the smallest maximum dynamic water pressure value. Technical and schedule analysis shows that the excavation period of Scheme 1 is the shortest, and the safety risk sources are relatively fewer. Taking into account various factors, Scheme 1 is recommended, as this method is more feasible in terms of improving construction efficiency, shortening the construction period, reducing safety risks, and optimizing the design.

In response to the design requirements for the first water diversion and power generation system's inclined tunnel TBM in China, this paper proposes and discusses the advantages and disadvantages of different design schemes, providing technical reference for similar projects in China.

Acknowledgments

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