

Research Article

Research on Visual Management Technology of Tunnel Construction Process Based on BIM Technology

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In order to achieve more efficient management of BIM technology in the field of tunnel construction, this paper took Zhuhai Dahengqinshan No. 1 Tunnel as the project background and studied the visualization management technology of tunnel construction process based on BIM technology. Firstly, we created the 3D geological model and tunnel BIM model by using Revit, 3dsmax, and other software. Secondly, the detailed design was carried out, and there was no gap in the model after the detailed design was checked by ABAQUS software. Then, we checked the problems between disciplines and conducted collision inspection in the model. Finally, we carried out the 4D construction progress simulation to solve the conflict between time and space in the whole life cycle of tunnel construction. The results revealed that the deepening design could optimize the design scheme of tunnel construction engineering. Collision inspection directly exposed problems such as unscientific site layout. 4D construction schedule management could not only realize the visualization of field construction process but also improve the quality of project management compared with traditional means. The research results provide technical experience for the visualization management of tunnel construction.

1. Introduction

Since the beginning of the twenty-first century, the construction of traffic tunnels in China has developed rapidly [1, 2]. The large area of highway tunnels has broken the restrictions between urban areas, thus driving the economic development around the tunnel. At present, more than 35 cities in China have urban rail transit, mainly subway. There are more than 3000 stations and 169 planned lines in China, with a total mileage of more than 5000 km [3–5]. Up to 2017, 15000 km of railway tunnels have been put into use in China, and more than 16,000 highway tunnels have been operated, with a total length of 15000 km [6–8].

However, the tunnel project has the characteristics of concealment, large volume, long construction period, and high construction requirements. The traditional schedule management is largely dependent on the engineering experience of managers. It is often only to optimize the schedule in the early stage of the project, which cannot show

the problems existing in the construction process. The lack of effective collaborative construction in each stage of the actual project is prone to delay the construction period [9–11].

BIM (Building Information Modeling) links the three-dimensional information model with schedule elements to realize visualization of the whole construction process and highly integrate project documents [12–14]. Compared with most projects only using PROJECT, P6, and other software for schedule management, BIM can better serve the visual management of tunnel construction by prefabricating site layout and formulating countermeasures in advance for problems encountered in the construction process [15–17].

Many scholars have applied BIM technology to the progress management of tunnel construction. IFC file can be used as the carrier of information interaction between platforms. Through 4DCAD technology, 3D terrain model, building model, and schedule can be combined to realize four-dimensional schedule management based on the IFC

standard [18, 19]. Wang et al. [20] introduced building information modeling and virtual reality technology into immersed tunnel engineering by combining with VR technology. Zhu et al. [21] proposed a standardized and refined modeling method for highway tunnels by using Civil3D, Revit, Dynamo, and other software, which solved the problem of spatial 3D surface modeling. This method is verified in the actual tunnel process. Song et al. [22, 23] introduced the role and advantages of BIM in design, construction, operation, and maintenance and provided guidance for integrated management based on practical engineering. Secondly, in view of the inconsistency of BIM standards in the whole life cycle of tunnel engineering, a BIM management platform for the whole life cycle is proposed to coordinate multiple levels, which lays the foundation for the application of the platform in practical engineering in the future.

On the basis of previous studies, taking Zhuhai Dahengqinshan No. 1 Tunnel as the project background, this paper carried out BIM technology application research on the establishment of three-dimensional geological model, tunnel model modeling, collision inspection, deepening design, and four-dimensional schedule management, which could realize the visualization of tunnel construction process. In this paper, we could formulate or optimize the construction scheme in advance for the conflicts in the construction. The research results provide experience reference for visual management of tunnel construction process.

2. Project Overview

Dahengqinshan Tunnel (phase I) is located in Hengqin Island, connecting Hengqin Avenue in the north and Qinhai South Road to be built in the south. It crosses Dahengqin Mountain, with a total length of 4.9 km. According to the plan, in the future, the tunnel will pass through Hengqin Avenue, connecting with Hengqin Tunnel in the north and with Zhuhai Avenue in the long term. It is one of the “aorta” of outreach in Hengqin Island. The design standard of Hengqinshan Tunnel is 60 km/h, which is a two-way 6-lane urban trunk road municipal tunnel. The section where the tunnel is located is the eroded residual hill landform, with residual soil (gravelly cohesive soil) covered on the surface of the mountain, and the basement is the granite of Yanshan Stage II-III. Dahengqinshan Tunnel is constructed by spray anchor support, composite lining, and CRD method. YK1 + 281 on the right and ZK1 + 289 on the left underpass the planned Zhujii urban rail tunnel. The vertical distance between the left line of Dahengqinshan Tunnel and Zhujii Tunnel is 4.36 m and 3.50 m on the right (Figure 1). According to the survey report, the topographic map of the survey area is shown in Figure 2.

3. Establishment of BIM Model

3.1. Tunnel Geological Model Modeling. In order to restore the real geological conditions of the geological model, this paper creates a three-dimensional geological model based on

the ‘point-surface-body’ construction model of Civil 3D [24–26]. First of all, using the high and low irregular pile foundation information, namely, the original measurement data and geological drilling information data, we integrate them into a triangular network to form a triangular surface. Through the three-dimensional observer, the abnormal points are excluded in the elevation range. The processed data information is imported into the software platforms such as Revit and 3dsmax for secondary terrain utilization. According to the generated terrain surface, the tunnel plane route design, longitudinal section design, and assembly design are carried out. Finally, the geological rock and soil body surrounded by the surface are obtained by using the Civil3D surface creation and entity extraction function to surround the geological layer surface. The specific modeling technical route and the formed geological surface model are shown in Figures 3 and 4, respectively.

3.2. Tunnel Model Modeling. According to the geological information and route direction of the project, the BIM model of Dahengqinshan Tunnel is formed by cross section lofting along the central line of the route. When the super-elevation part of the tunnel cross section appears, the super-elevation value of the radius of the horizontal curve is given and loaded into the tunnel cross section. In this process, the cross section changes dynamically with the change of the pile number. Finally, the separated tunnel model is generated through component lofting (Figure 5).

3.3. Construction Monitoring Visualization. We compare the BIM model of each discipline with the drawings and model data provided by the owner for model integrity review. Problems between single specialty and multispecialty were found in the model inspection. Table 1 shows the single specialty model problem.

According to the process of BIM model deepening design, the model of the research object is optimized, including specialty internal deepening, multispecialty comprehensive optimization, and standardization of reserved holes. The principles and methods of model optimization are put forward (Table 2).

4. Analysis of Shield Tunnel Construction Scheme

4.1. Collision Check. The collision check function of BIM technology can allow quick identification of hard collision, soft collision, and duplicate items in the model [27–29]. Compared with the previous omissions caused by relevant personnel modifying the design scheme through two-dimensional drawings and personal spatial imagination, Navisworks’ powerful “clash detective” function greatly improves the work efficiency. The resulting collision inspection report shows that there are 514 structural conflicts between different majors. Finally, the BIM model is modified according to the inspection results.

The errors can be divided into five types: collision between ① sprayed arch wall and arch wall lining; ② 3# plug

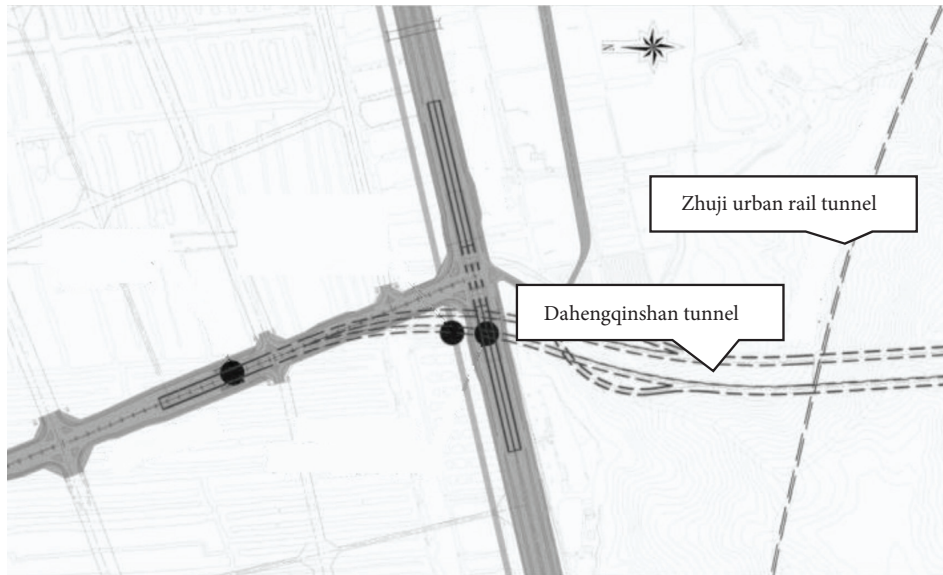


FIGURE 1: Plane position relationship between Dahengqinshan Tunnel and Zhuji Tunnel.

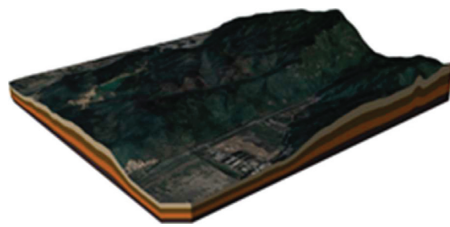


FIGURE 2: Topographic overview.

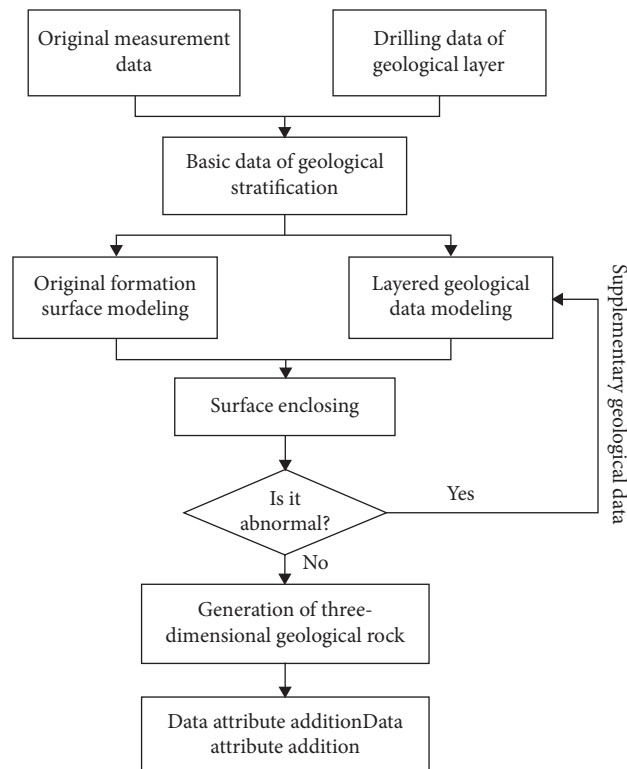


FIGURE 3: Modeling technology roadmap.

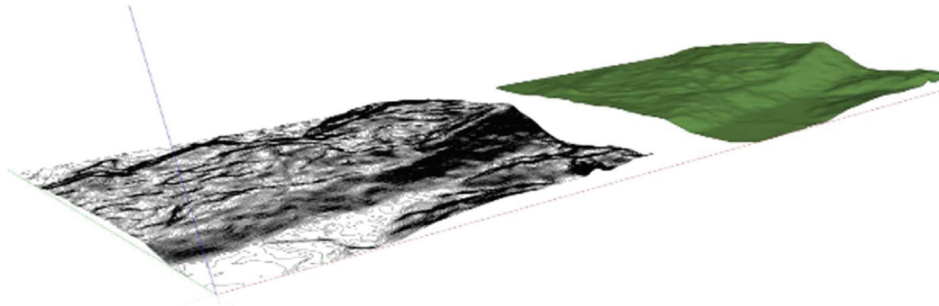


FIGURE 4: Geological model.

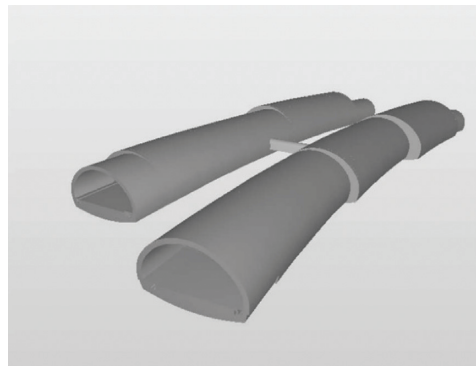


FIGURE 5: Tunnel model.

TABLE 1: Model problems.

Specialty	Problems
Comparison between civil engineering model and drawing	<p>There will be overlaps and gaps between sprayed arch walls</p> <p>There will be overlaps and gaps between arch wall linings</p> <p>3# plug wall of left line and sprayed arch wall cannot be closed</p> <p>There will be overlaps and gaps between invert arch linings</p> <p>There will be overlaps and gaps between shotcrete linings</p> <p>3# plug wall of left line and arch wall lining cannot be closed</p> <p>3# plug wall of left line and invert arch lining cannot be closed</p> <p>There is a gap between tunnel pipe sections, which cannot be closed</p> <p>Overlaps and gaps will be formed between inverted arch filling</p>

wall of left line and sprayed arch wall; ③ 3# plug wall of left line and shotcrete lining; ④ invert arch lining and sprayed arch wall; and ⑤ shotcrete lining and 3# plug wall of left line.

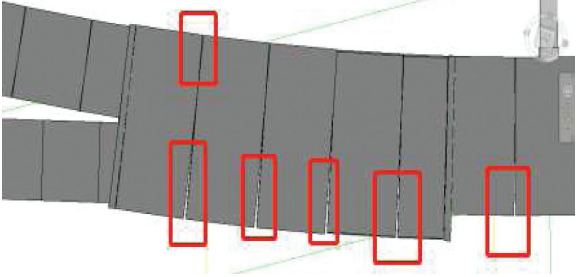

Figure 6 shows the hard collision between several tunnel structures.

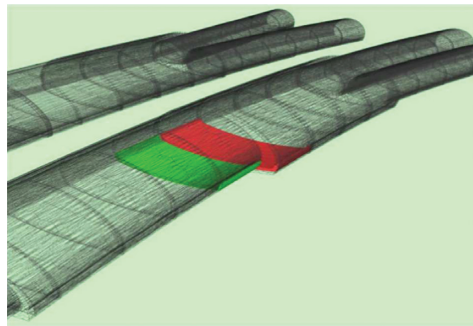
4.2. Visualization Analysis of Construction Monitoring.

Based on the characteristics of BIM information integration and according to the layout scheme of measuring points of Dahengqinshan Tunnel at the intersection, the displacement sensors and velocity sensors arranged at the arch crown, arch bottom, and arch waist are visually displayed in the BIM model. The sensor model is created with the help of Revit software. At the same time, the sensor family is defined and the geometric appearance of the

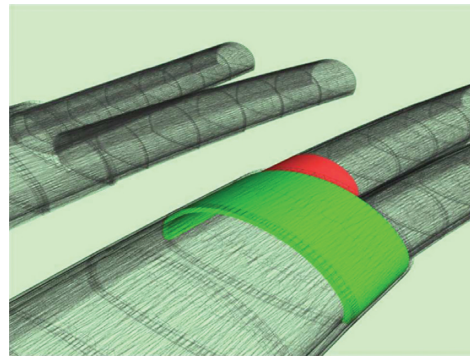
sensor entity is created. The sensors on the model are associated with the monitoring information collected in the field construction to facilitate the recording of monitoring data. Because the sensor model in this paper mainly realizes the function of information expression and three-dimensional positioning, in order to make the BIM model lightweight, the sensor entity is simplified. Figure 7 shows the layout and geometric appearance of sensors on the tunnel section. The visualization of construction monitoring can realize the automatic input of monitoring point information and monitoring data. Compared with the traditional manual data recording and excel table sorting and calculation, the BIM tunnel safety monitoring method can ensure the authenticity of the original data and greatly improve the efficiency of construction information processing.

TABLE 2: Professional internal deepening table.

Specialty	Optimization principle	Optimization reason
Tunnel structure	Tunnel joints close connection	Overlaps and gaps between tunnel sections
Optimization suggestion	Modify the model to make the tunnel element tightly connected	
Problem description	First process the tunnel model with Revit, modify the tunnel pipe joints so that there is no gap between the pipe joints, and then cut off the overlapping places of the tunnel pipe joints with ABAQUS to make the tunnel pipe joints closely connected	
Problem diagram		
Deepened model		



(a)



(b)

FIGURE 6: Impact member display: (a) collision between sprayed arch wall and arch wall lining; (b) collision between invert arch lining and sprayed arch wall.

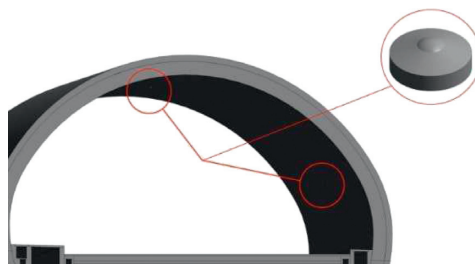


FIGURE 7: Sensor placement and geometric appearance.

5. 4D Construction Schedule Management of Shield Tunnel

In this paper, the construction process of A ramp and 1# tunnel right hole and B ramp and 1# tunnel left hole excavation in the construction organization design of Dahengqinshan Tunnel project is simulated in combination with the start and completion time of each work, and the corresponding progress analysis is carried out [30, 31].

5.1. 4D Construction Progress Simulation. In the process of project site schedule management, schedule tasks are decomposed according to WBS by introducing BIM technology. We use PROJECT software to create A ramp and 1# tunnel right hole, B ramp and 1# tunnel left hole excavation, and other stages of the construction process schedule. The BIM model and schedule is imported into Navisworks software for schedule simulation to show the dynamic change of overall schedule. In the actual construction, the plan is dynamically optimized and adjusted in real-time according to the actual construction progress so as to achieve the comprehensive, real-time, reasonable, and effective goal of schedule management. The main process is shown in Figure 8.

5.1.1. Preparation of Project Schedules at All Levels. (1) Establishment of WBS. According to the construction risk factors and management characteristics of the CRD method in Dahengqinshan Tunnel (phase I) project, each construction process is split and displayed. Taking the section as the basic unit, the tunnel project is divided into three basic works: extended support, initial support, and secondary lining structure construction. Finally, the overall schedule of Dahengqinshan Tunnel is obtained (Table 3).

(2) Preparation of Project Schedule. In this paper, the project management software is used to prepare the logical relationship and time arrangement of flow construction in the overall project and the three basic works according to the total construction period requirements and the total investment arrangement of the project, combined with the specific conditions such as the general layout, construction technical scheme, and construction process selection of the project. According to the overall plan of the project, the 4D schedule simulation schedule table of project management software is compiled, and the table is imported into Navisworks to form a schedule file.

5.1.2. Simulation of Four-Dimensional Construction Progress. The original 1 schedule (excavating the entrance tunnel body of ramp a tunnel and 1# tunnel right tunnel and carrying out initial support, with a single tunnel length of 1174.585 linear meters) is completed on September 8, 2018. Assuming that the actual progress of the project is on 30 September 2018, the actual completion time is delayed by 21 days compared with the planned time, which needs to be optimized.

The four-dimensional construction simulation based on BIM can optimize the management in two aspects:

firstly, it can visually manage the whole construction process of tunnel engineering construction and then optimize the resource allocation; secondly, through construction simulation, we can study and obtain the technical key points that may affect the construction period in the whole construction process and optimize the construction scheme in advance, so as to ensure that the project is promoted as planned.

In the specific operation, in order to ensure that the progress plan can be accurately matched with the corresponding model construction, the progress information model of the plan is continuously generated in BIM according to the tunnel mileage pile number. At the same time, the Project file with construction progress data is exported to “.MPP” format. The “timeliner” function is used to connect each WBS task with each component one by one so as to realize the effective connection between BIM model and schedule task and establish the 4D model of BIM of tunnel engineering. Figure 9 shows the setting of the display effect at different stages in the four-dimensional simulation and the actual effect of the planned progress simulation.

5.1.3. Four-Dimensional Progress Control. The dynamic simulation of the whole construction process is carried out according to the set construction schedule. In the implementation process of specific projects, through the comparative analysis between actual progress and planned progress in the BIM growth model, combined with various possible influencing factors on the site, the progress plan can be updated and adjusted in a timely manner to ensure the realization of the duration goal.

5.2. Specific Results of 4D Simulation. On the basis of ensuring the seriousness of the progress plan, through four-dimensional progress simulation and progress control, combined with on-site progress feedback and dynamic adjustment, BIM application results are as follows:

- (1) BIM visually shows the construction process of the tunnel in the form of animation so that the staff can clearly understand the operation of each period. Through on-site three-dimensional roaming (Figure 10), the problem of overlapping traditional two-dimensional graphic lines is solved, which reflects the characteristics of humanized design of BIM software modeling.
- (2) Through the BIM model engineering quantity calculation and combined with the actual difficulty of engineering implementation, the engineering plan is prepared to improve the accuracy of the comprehensive construction plan. Through the four-dimensional construction progress simulation, it is foreseen that there are many problems in the implementation of the original plan, such as the conflict of work space and the unreasonable logical relationship of work, and an overall optimization and adjustment of the progress plan are carried out.

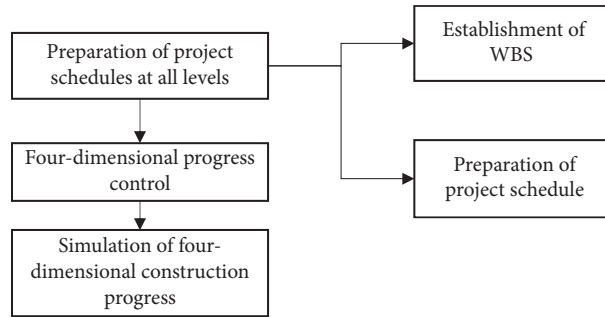


FIGURE 8: Construction progress simulation process.

TABLE 3: Overall project schedule.

Job content	Start time	Execution time
Tunnel portal reinforcement	July 10, 2018	November 1, 2018
Construction of 1# tunnel open cut section	October 20, 2018	May 17, 2019
Tunnel body excavation and initial support of ramp A tunnel and right tunnel entrance of 1# tunnel (single tunnel length 1174.585 linear meters)	September 8, 2018	December 16, 2019
The second lining, waterproof and drainage, and concrete pavement of ramp A tunnel and right hole entrance of 1# tunnel (single tunnel length 1174.585 linear meters)	November 8, 2018	March 31, 2020
Tunnel body excavation and initial support of ramp B tunnel and left tunnel entrance of 1# tunnel (single tunnel length 1212 linear meters)	October 5, 2018	December 11, 2019
The second lining, waterproof and drainage, and concrete pavement of ramp B tunnel and left hole entrance of 1# tunnel (single tunnel length 1212 linear meters)	December 5, 2018	March 31, 2020
Excavation and initial support at the outlet of the right tunnel of 1# tunnel (single tunnel length 1232 linear meters)	November 16, 2018	December 9, 2019
The secondary lining, waterproof and drainage, and concrete pavement at the outlet of the right tunnel of 1# tunnel (single tunnel length 1232 linear meters)	September 16, 2018	March 31, 2020
Excavation and initial support at the outlet of the left tunnel of 1# tunnel (single tunnel length 1265 linear meters)	September 25, 2018	December 20, 2019
The second lining, waterproof and drainage, and concrete pavement at the outlet of the left tunnel of 1# tunnel (single tunnel length 1265 meters)	November 25, 2018	March 31, 2020
Excavation and initial support of right entrance of 2# tunnel (single tunnel length 1185 linear meters)	September 12, 2018	October 28, 2019
The second lining, waterproof and drainage, and concrete pavement at the entrance of the right tunnel of 2# tunnel (single tunnel length 1185 meters)	November 12, 2018	March 31, 2020
Excavation and initial support of left entrance of 2# tunnel (single tunnel length 1155 linear meters)	September 20, 2018	September 6, 2019
The second lining, waterproof and drainage, and concrete pavement at the entrance of the left tunnel of 2# tunnel (single tunnel length 1155 meters)	November 20, 2018	March 31, 2020
Excavation and initial support at the outlet of the right tunnel of 2# tunnel (single tunnel length 1036 linear meters)	November 1, 2018	October 3, 2019
The secondary lining, waterproof and drainage, and concrete pavement at the outlet of the right tunnel of 2# tunnel (single tunnel length 1036 linear meters)	January 1, 2019	March 31, 2020
Excavation and initial support at the outlet of the left tunnel of 2# tunnel (single tunnel length 1085.451 linear meters)	October 25, 2018	December 1, 2019
The secondary lining, waterproof and drainage, and concrete pavement at the outlet of the left tunnel of 2# tunnel (single tunnel length 1085.451 linear meters)	December 25, 2018	March 31, 2020

Tunnel engineering

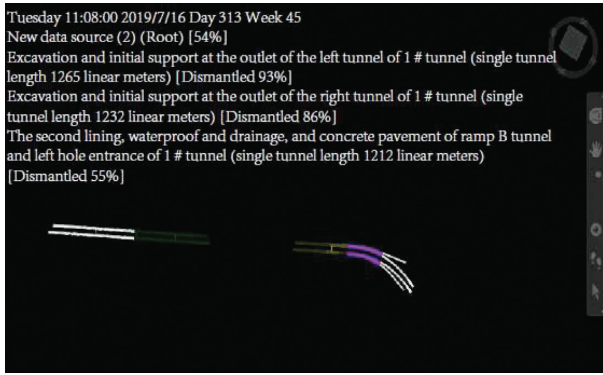


FIGURE 9: Four-dimensional construction schedule simulation process.

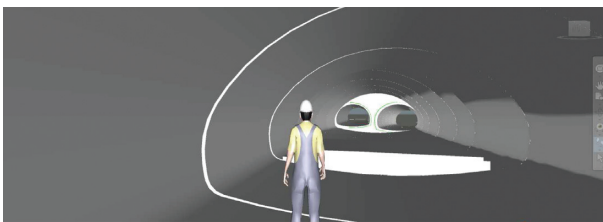


FIGURE 10: 3D roaming display of site construction.

6. Conclusions

Aiming at the problems of concealment, long construction period, and low construction efficiency in tunnel construction, combined with Dahengqinshan Tunnel project and based on BIM technology, this paper establishes a three-dimensional geological model and carries out three-dimensional modeling, deepening design, collision inspection, and 4D schedule management of the tunnel. The specific conclusions are as follows:

- (1) We use BIM software to carry out three-dimensional tunnel modeling and deepen the design of the model to solve the problems of single discipline and multidiscipline. Compared with the traditional two-dimensional drawing design, the three-dimensional model ensures the integrity of the tunnel model. At the same time, BIM can make visual disclosure to help relevant personnel of later projects fully understand the four-dimensional construction process of the tunnel.
- (2) Secondly, we carry out the structural collision inspection during the construction process and find a total of 514 structural conflicts. These structural conflicts are often difficult to find because they do not violate the design specifications. In this process, relevant personnel can optimize and adjust the design scheme in the model.
- (3) Finally, the 4D construction technology management of Zhuji Tunnel is carried out to find the conflict between time and space in the construction process in advance. On this basis, the schedule is

modified to ensure the construction progress. It is more conducive to command on-site construction than the traditional adjustment of the construction scheme based on the engineering experience of construction management personnel.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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