Dust Migration Law in Working Area of Large Cross-section Tunnel by Mining Method

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Abstract. At present, there is no pertinence in the law of dust migration in the tunnel construction by mining method, although there are abundant researches. This paper studies the Qintai Tiantaishan tunnel through field measurement and numerical simulation, and analyzes the dust migration law under the conditions of drilling, mucking and guniting for the working area. The results show that: (1) Under all working conditions, the dust concentration tends to decrease in the area along tunnel face. And the higher the dust concentration, the more significant the decreasing trend. (2) When the dust concentration is small, there will be fluctuation trend. What’s more, the smaller the dust concentration, the earlier the trend appears. (3) The dust concentration under all working conditions exceeds the specification limit. Among them, the dust concentration is the highest under the condition of mucking, the next under the condition of drilling, and the lowest under the condition of guniting.

1. Introduction

The mining method is one of the important construction techniques of tunnel construction, which is suitable for many surrounding rock conditions. However, a large amount of dust will be produced in the tunnel construction process, which will pollute the air environment in the tunnel and cause damage to the health of tunnel construction personnel. Long-term inhalation of respiratory dust will cause pneumoconiosis [1].

At present, there are many researches abroad. Based on the study of aerosol mechanics, Fuchs [2] described the movement of dust in the air. Under the condition of central symmetry of roadway section, Courtney [3] deduced the expression of dust concentration distribution along the road. By studying the law of dust action in the air flow, Bhskar [4] established the dust convection diffusion equation under the condition of one-dimensional steady and uniform flow.

Relevant research has also been done in China. Jingde Xu [5-6] has carried out dust migration experiments. The results show that the dust concentration in the lower half of the roadway is higher than that in the upper half and that the dust migration law along the road under different wind speeds has been obtained. Zhongqiang Sun [7] conducted field measurement, numerical simulation and similar experiment on Xinzhuang tunnel of Beijing Kunming expressway. The results show that the dust concentration gradually increases from top to bottom in the vertical direction of the same section.
Along the tunnel, with the increase of the distance from the tunnel face, the dust concentration gradually decreases.

Based on the research status at home and abroad, relevant researchers have made some achievements in the research of dust migration law. But the study of dust migration laws is limited. Therefore, this paper studies the dust migration laws in highway tunnels in tunnel construction area.

2. Project overview
The prototype of the tunnel studied in this paper is Qinling Tiantaishan highway tunnel, which is the control project of Baoji Pingkan Expressway and the longest two-way six lane highway tunnel in the world, with a total length of 15.5km [8].

According to the site conditions, Tunnel face has been located in the class III surrounding rock section at that moment. The method of full section blasting has been adopted in the tunnel, with the section area of 98.3m². What’s more, the excavation of 1.3km has been completed on the left and right lines of the main tunnel on average. The first independence press-in technology of ventilation has been adopted to provide fresh air for the tunnel. The diameter of the air duct is 1.8m, with the duct end 60m away from tunnel face.

The personnel in the tunnel are mainly working in the area from tunnel face to the secondary lining. According to the field measurement, the working area of the secondary lining is 200m away from tunnel face. In order to show the dust concentration in this area more clearly, the length of field measurement and numerical simulation is determined as 300m.

3. Field measurement
The instrument used in field measurement is direct reading dust detector, which is widely used in tunnel engineering [9], construction engineering [10] and coal mine engineering. The main principle of the instrument is the method of membrane weight measurement.

The layout of field measuring points is shown in Figure 1. The measuring points are arranged at the distance from 40m to 290m along tunnel face. Each measuring point is arranged once every 25 m interval, counted as “Z + ‘distance from the measuring section to tunnel face’”. The measuring item is the total dust concentration value, which refers to the mass of dust suspended in the air per unit volume (mg/m³) [11].

In consideration of the height of the breathing part of the staff, the measuring points are arranged at a height of 1.5m to the subgrade at the middle line of the tunnel. According to the relevant specifications, each measuring point is tested 5 times, taking the average value as the dust concentration.

![Figure 1. Figure of measuring points under field measurement](image_url)

The field measurement were carried out under conditions of drilling, mucking and guniting respectively. At the blasting condition, the workers in the tunnel have left the tunnel or have been far
away from tunnel face, not exposed to high concentration dust. Therefore, the field measurement and numerical simulation under this condition are not carried out.

4. Numerical simulation

4.1. Numerical simulation method

The movement of dust in the tunnel belongs to the gas-solid two-phase flow. The current numerical simulation methods for studying the gas-solid two-phase flow include the Euler-Lagragian method and the Euler-Eulerian method.

In the Euler-Lagragian method, there is exchange of momentum, mass and energy between the discrete phase and the fluid phase. The method is applicable on the premise that the volume fraction of the second phase as the discrete phase should be small, generally less than 10%. The Fluent model corresponding to the Euler-Lagrangian method is DPM.

In this paper, DPM of Euler-Lagrangian method is used. The airflow in the tunnel is regarded as the continuous phase. Dust is regarded as the discrete phase distributed in the background fluid.

4.2. Basic assumption

According to the actual situation on site, the 300m area from tunnel face is simply simulated. During the numerical simulation, the following assumptions are proposed.

1. It is assumed that pipelines other than air duct in the tunnel will not affect the numerical simulation.
2. It is assumed that the staff in the tunnel will not affect the numerical simulation.
3. It is assumed that the machinery in the tunnel has no influence on the numerical simulation.
4. It is assumed that there is no secondary dust in the tunnel.

4.3. Numerical model

On the basis of the above assumptions, the model is reasonably simplified in combination with actual situation on site. At the same time, the model is drawn in ANSYS ICEM CFD software.

![Figure 2. Figure of numerical simulation model](image)

In the drilling condition, there are 6 groups of workers operating the drilling rig at the same time. These boreholes are simulated with a circular plane with a diameter of 0.04m. The mucking face is composed of the lower part of tunnel face and the subgrade, which are simulated by two faces. The working face under guniting condition is 5m away from tunnel face. And the surface is 5m wide, simulated by arc surface.

4.4. Numerical simulation results

During the simulation, the simulation of air flow is performed firstly. Then, the coupling simulation is calculated after the dust source is added to the working face of the drilling condition, the mucking
condition or the guniting condition. Finally, the simulation is completed and the corresponding results are exported.

![Figure 3. Figure of numerical simulation results under drilling condition](image)

The fresh air is ejected from the duct end, which impacts tunnel face with a large area of air flow. At the same time, the dust generated at the working face diffuses outwards at a certain speed. The air flow arriving at tunnel face produces reflexive reflux, which carries the produced dust to move together. In the subsequent migration process, part of the dust is suspended in the eddy current area, part of the dust settles, and part of the dust diffuses outward.

5. Results and analysis

Figure 4 shows the results of field measurement and numerical simulation. In the working area, the dust concentration presents a downward trend along tunnel face. And the higher the dust concentration is, the more significant the dust concentration downward trend is. Fluctuations occur when the dust concentration is small. The smaller the dust concentration is, the earlier the trend will appear.

Dust concentration exceeds the standard limit (2mg/m$^3$) under various working conditions. Among them, the dust concentration is the highest under the mucking condition, with the 12 times of the specification limit. The dust concentration is the second highest under drilling condition, reaching 6 times of the standard limit value. Under the condition of guniting, the dust concentration is the minimum, which is about 3 times of the standard limit value.

![Figure 4. Dust concentration diagram under various working conditions](image)

The results of field measurement in the figure are in good agreement with that of numerical simulation. Therefore, it can be concluded that the diffusion rule of dust concentration derived from numerical simulation is basically the same as that of field measurement.

In Figure 4(c), the results of the two methods are in low agreement. It is mainly caused by the following factors:

1. The influence of the environment in field measurement.
2. The obstruction of the personnel in field measurement.
3. The instrumental error in field measurement.
4. The operate miss in field measurement.
The idealization of the model in numerical simulation.

6. Conclusion
Through the analysis of the field measurement and numerical simulation results, the following conclusions can be obtained.

(1) The results of field measurement are basically consistent with that of numerical simulation.
(2) In the working area, the dust concentration presents a downward trend along tunnel face. And the higher the dust concentration is, the more significant the dust concentration downward trend is.
(3) Fluctuations occur when the dust concentration is small. The smaller the dust concentration is, the earlier the trend will appear.
(4) Dust concentration exceeds the standard limit under various working conditions. Among them, the dust concentration is the highest under the mucking condition, with the 12 times of the specification limit. The dust concentration is the second highest under drilling condition, reaching 6 times of the standard limit value. Under the condition of guniting, the dust concentration is the minimum, which is about 3 times of the standard limit value.

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