Monitoring Study on Dust Diffusion in High Altitude Tunnel under Drilling and Muck Removal Conditions

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Abstract: In the high altitude area, the air density and the air pressure are low. In this paper, combined with a high altitude tunnel engineering in Tibet, the dust concentration during the drilling and muck removal was monitored, and tunnel dust diffusion situation was analyzed. The result shows that the dust concentration on the middle line of tunnel is higher than the dust concentration at the tunnel side. The dust concentration near the tunnel face is the highest. In the longitudinal direction, the change rule of the total dust and respirable dust concentration, are totally the same. With the increase of distance from tunnel face, dust concentration declines rapidly, then gradually become stable. The dust diffusion rule in the process of muck removal is basically similar to that of drilling process, but the dust concentration is larger, and the concentration of respirable dust accounts for a higher proportion than that in the drilling operation.

1. Introduction
With rapid development of tunneling projects in China and increasing emphasis placed on occupational health in recent years, tunnel dust diffusion patterns in construction environment and prevention and control measures have been the focus of research. From a large number of actual projects, foreign researchers have gained valuable engineering experience and fruitful research results in construction ventilation. Mariano demonstrated through research that particle inertia is a key factor influencing the dynamics of dust particulate. Wang performed experiments on coal dust with an average size of 60μm and found that particles flow faster than air in boundary layer and that momentum transfer exists between them. Isabelle et al. pointed out that dust concentration in the mine is related to particle size distribution in coal seam. In China, Du Cuifeng performed an experiment on dust distribution in coal mine under mixed ventilation condition and developed dust reducing agent formula. Tan Cong analyzed factors influencing dust distribution on the working face of mine on the basis of two-phase flow theory. Tao Kun investigated fluid in expressway tunnels under forced ventilation and noted the concentration of hazardous substance in tunnel ventilation area is inversely proportional to air flow. He Qingqing divided the blind heading tunnel into wall-attached-jet zone, impact jet flow zone and return flow zone, studied air flow patterns in each zone and developed a numerical model and solution of jet flow ventilation for blind heading tunnels. Through calculation and analysis of a highway tunnel model, Liu Zhao obtained the characteristics of dust flow field variation over time during tunneling.
Ventilation is particularly important in high altitude areas where air density is low, atmospheric pressure is low, ambient temperature is low and oxygen concentration is low. However insufficient research has been conducted into tunnel dust movement characteristics in high altitude areas. In the context of an actual tunneling project at a high altitude in Tibet, this paper covers measurement of dust concentration generated by drilling and muck removal using dust monitoring instruments and analysis of dust diffusion patterns in the tunnel.

2. Mechanism and Classification of Dust Generated during Tunneling
During construction of a mined tunnel, drilling, blasting, muck removal and shotcrete application will all produce dust. Some dusts which have fallen to the ground are likely to be blown by air flow and suspend in the air, causing secondary dust pollution in the entire tunnel. In addition, muck transport and removal require excavation operation in which the muck loader places muck into the tipping bucket which pours the muck into a truck. This process will produce large amounts of dust. Currently, dust is classified by particle size as follows:

(1) Coarse dust: diameter ≥40μm; such dust can quickly settle in the air by gravity.
(2) Fine dust: 40μm > diameter ≥10μm; such dust is visible to bare eye and settles in an accelerated way in the air because its buoyancy is less than gravity.
(3) Particulate dust: 10μm > diameter ≥0.25μm; such dust is invisible to bare eye and settles at constant speed in still air because its buoyancy is approximately equal to gravity.
(4) Superfine dust: diameter < 0.25μm; such dust can suspend in air for a long time and act in Brownian motion along with air molecules.

Depending on the hazard level posed by dust to physiological functions of human body, dust can also be classified into respirable dust, non-respirable dust and total dust. Respirable dust means dust of less than 7μm in size that can enter the lung through the respiratory system and disable the lung. Non-respirable dust is dust of greater than 7μm in size, most of which can disappear through natural settlement. The rest that cannot settle will be blocked from entering human body by the respiratory system and will thus not cause serious damage to the body. Therefore, respirable dust is the focus of dust prevention and control during construction of highway tunnels.

3. Monitoring Scheme for Dust Diffusion in High Altitude Tunnel
Since air pressure and temperature are inversely proportional to altitude, high altitude areas have lower air pressure and temperature. Meanwhile, dust diffusion is related to air density, humidity and other conditions. As a result, dust diffusion patterns in a high altitude tunnel are different from a tunnel at normal altitude. To better understand the actual dust diffusion patterns in high altitude areas, this paper presents a scheme to monitor dust during construction of an expressway tunnel in Tibet. The tunnel site area is at 4100m~4500m above sea level. Considering safety and monitoring cost, this experiment is mainly focused on dust diffusion during drilling and muck removal.

This tunnel is a four-lane expressway tunnel with a maximum longitudinal gradient of ±3%, located in a fluctuating area with high mountains, steep slopes and developed gullies in east-west direction. Hill-low mountain landform resulting from denudation and deep cutting is seen on the surface where relative cut depth is 190m and large areas of bedrock are exposed. The tunnel is buried at 59.59~69.38m depths and its maximum design excavation width is 18m.

GCG1000 dust concentration sensor is used to monitor dust. It works on the principle that scattered light intensity from the dust is proportional to its mass concentration. It radiates infrared laser on suspended dust using infrared laser and imported photomultiplier and converts scattered light intensity to electrical signal to calculate dust mass concentration. Fig. 1 gives the layout of monitoring points on the tunnel site. During drilling, the longitudinal spacing of dust monitoring points is L=4m; during muck removal, the longitudinal spacing of dust monitoring points is L=8m. Three rows of monitoring lines are arranged at a distance of 2m, 8m and 14m from the right side (air duct side) and at a height of about 1.6m from the tunnel floor. During drilling 9 monitoring points are arranged on the monitoring line whereas
during muck removal 6 are arranged. The dust sampler takes samples for 20min. Based on measurements dust concentration distribution curves are plotted.

Fig. 1 Layout of monitoring points

4. Analysis of Dust Diffusion During Drilling

Fig. 2 Distribution of dust 14m from the air duct  Fig. 3 Distribution of dust 8m from the air duct

Fig. 4 Distribution of dust 2m from the air duct

From dust distribution illustrated in Fig. 2-4, the following analysis results are obtained:

Overall, dust concentration on the centerline of the tunnel (8m from air duct) is higher than on either side. Dust concentration on the centerline of the tunnel in proximity to the tunnel face is the highest, with maximum total dust concentration reaching 60mg/m³ and maximum respirable dust concentration reaching 32mg/m³. In terms of the three monitoring lines, dust concentration on the side with air duct is much lower than the side without air duct on the same section, because fresh air from the air duct is blown to the tunnel face reducing dust concentration on this side while some of the dust is moved to the other side by the air flow. In addition, total dust concentration changes in the longitudinal direction of
the tunnel in basically the same way as respirable dust concentration: as the distance from the tunnel face increases, dust concentration quickly drops until it stabilizes with small fluctuations.

From the proportion of respirable dust in the above 3 figures it can be seen that the proportion of respirable dust produced during this process is high at above 48%; the proportion of respirable dust on the side without air duct is the highest averaging 63%, especially at 15m-30m from the tunnel face where the proportion approaches 100%. This is because at the low atmospheric pressure in high altitude areas, large size dust keeps settling under the effects of gravity and resistance with increasing distance from the tunnel face while small size dust is more likely to spread to the entire tunnel space, thus increasing the proportion of respirable dust.

5. Analysis of Dust Diffusion During Muck Removal

From dust distribution illustrated in Fig. 5-7, the following analysis results are obtained:

Similar to the drilling process, dust concentration on the centerline of the tunnel is higher than on either side during muck removal. Dust concentration is distributed along the length of the tunnel in roughly the same pattern: first abruptly falling, then fluctuating and finally stabilizing.

Forklift, truck and other equipment mainly operate at 0~15m from the tunnel face, causing particulates inherent in blasting debris to fly into the air, so dust concentration peaks in this area with maximum total dust concentration on the centerline nearly 90mg/m³ and maximum respirable dust concentration nearly 66mg/m³. The proportion of respirable dust concentration is higher (at 67% on average) than during drilling.

Comparison of respirable dust proportions in the above 3 figures shows the proportion of respirable dust on the centerline and on the side without air duct is the highest averaging 72%, on a trend of "falling, gradually rising and then stabilizing". This because flying dust induced by forklift and truck operation contains large amounts of respirable dust which tends to suspend in the air due to the low atmospheric
pressure in high altitude areas. On the entire monitoring line, total dust concentration is high because during movement along with the air flow, the dust produced by muck removal operation mingles with the dust generated when trucks travel down the bench, pass arch bridge and meet other trucks.

6. Conclusions
From study on dust diffusion during construction of high altitude tunnels in this paper, the following conclusions can be drawn:

(1) Overall, dust concentration on the centerline of the tunnel is higher than on either side. Dust concentration on the centerline of the tunnel in proximity to the tunnel face is the highest. Dust concentration on the side of air duct is much lower than on the side without air duct on the same section. Total dust concentration changes in the longitudinal direction of the tunnel in basically the same way as respirable dust concentration: as the distance from the tunnel face increases, dust concentration quickly drops until it stabilizes.

(2) During drilling, the proportion of respirable dust on the side without air duct peaks at nearly 100% at a distance of 15m-30m from the tunnel face, because at the low atmospheric pressure in high altitude areas, large size dust keeps settling under the effects of gravity and resistance with increasing distance from the tunnel face while small size dust is more likely to spread to the entire tunnel space, thus increasing the proportion of respirable dust.

(3) The patterns of dust diffusion during muck removal are roughly similar to those during drilling operation but dust concentration is higher with maximum total dust concentration on the centerline nearly 90mg/m³ and maximum respirable dust concentration nearly 66mg/m³. The proportion of respirable dust concentration is higher (at 67% on average) than during drilling. This calls for more dust prevention measures.

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