Monitoring Study on CO and Dust Diffusion in High Altitude Tunnel under Blasting Operation

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Abstract: In the high altitude area, the air density and the air pressure are low. CO and dust diffusion in tunnel construction have special rules. In this paper, combined with a high altitude tunnel engineering in Tibet, CO and dust diffusion during blasting operation was monitored, and diffusion situation before adopting treatment measures was compared with that after adopting treatment measures. The result shows concentration of CO and dust produced by blasting operations is high, which is more likely to cause damage to operators in areas with thin oxygen at high altitudes. Therefore, necessary treatment measures should be taken. In the longitudinal direction, the change rule of the CO and dust are totally the same. With the increase of distance from tunnel face, dust concentration declines gradually. In the range of 100m~500m from tunnel face, the disadvantage effect of blasting is little. In this project, CO and dust concentration are reduced to a certain extent after the measures of strengthening ventilation and dust removal by water curtain are adopted.

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. Gidhagen built a three-dimensional numerical model of the ventilation system for a long road tunnel and investigated air flow distribution and pollutant transport mechanism in steady state. In China, Du Cuifeng performed an experiment on dust distribution in coal mine under mixed ventilation condition and developed dust reducing agent formula. In view of low atmospheric pressure and low work efficiency of workers at high altitudes, Zhao Junxi, Wei Yanqing et al. analyzed influencing factors of ventilator pressure and required air rate in a high altitude area and developed auxiliary ventilation measures suitable for construction of a high altitude tunnel. Tan Cong analyzed factors influencing dust distribution on the working face of mine on the basis of two-phase flow theory. Yuan Yulin et al. studied ventilation characteristics during construction of a high altitude tunnel and their constraints on construction organization. Xie Zunxian studied harmful gas emission...
characteristics during mechanized construction of a plateau tunnel and discussed health standard for the corresponding construction environment. Gou Hongsong et al. \cite{11} calculated ventilation air rate and selected the type of fans for construction of tunnels in a high altitude area.

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 harmful gas and dust movement characteristics for tunneling in high altitude areas. In the context of an actual high altitude tunneling project in Tibet, this paper covers field monitoring of CO and dust concentration from blasting operation using monitoring instrumentation, analysis of CO and dust diffusion patterns inside the tunnel and comparison of CO and dust concentration distribution before and after control measures are taken.

2. Mechanism of Harmful Gas and Dust Generation 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) Ultrafine 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.

In addition, insufficient combustion due to a lack of oxygen inside the tunnel produces harmful gases such as CO and NO. This will worsen air pollution inside the tunnel and pose a serious threat to workers' physical health. Consequently, it is important to monitor harmful gases inside the tunnel in addition to dust.

3. Monitoring Scheme for Harmful Gas and Dust in High Altitude Tunnel

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. The tunnel is 6300m long with composite linings. It is located in an area without fault structure. 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.

The high altitude, low air temperature, low atmospheric pressure and low oxygen partial pressure in the tunnel site area place high demands on workers' physical fitness. The dust and harmful gas during tunneling, if not effectively controlled, will cause more serious damage to human body under the low-atmospheric-pressure condition on the plateau. This monitoring focuses on CO and dust diffusion during blasting.

Dust concentration sensors are used to monitor dust. They work on the principle that scattered light intensity from the dust is proportional to its mass concentration. They radiate infrared laser on
suspended dust using infrared laser and imported photomultiplier and converts scattered light intensity to electrical signal to calculate dust mass concentration. A portable instrument is employed to monitor CO. Monitoring points are located on the tunnel centerline and spaced 5m apart in a range of 0~50m from the tunnel face; meanwhile, dust monitoring points are spaced 100m apart in a range of 100m~500m from the tunnel face. The duration of monitoring for all the monitoring points is 10min after blasting.

4. Analysis of Patterns of Harmful Gas and Dust Diffusion Under Blasting Condition

CO concentration is a key factor contributing to air quality inside the tunnel, especially in a high altitude area where insufficient oxygen and high CO concentration will seriously threaten the health of workers in the tunnel. Fig. 1 displays the distribution of CO concentration near the tunnel face after blasting.

As shown, CO concentration is high within 50m from the tunnel face after blasting and the maximum value is nearly 330mg/m³. Technical Specifications for Construction of Highway Tunnel[12] specifies that maximum allowable concentration of CO is 30 mg/m³. Inhalation of air containing CO at 292.5mg/m³ for 3 hours can lead to such symptoms as serious headache and dizziness. The monitoring data show the CO concentration near the tunnel face after blasting is much higher than the specified limit. Workers shall wear PPE and measures are required to control CO concentration.

The anoxic environment at high altitudes will also worsen the damage of dust to human body. Fig. 2 displays the distribution of dust concentration near and far away from the tunnel face after blasting.

As shown by the above monitoring data, dust concentration resulting from blasting is very high, with maximum total dust concentration reaching nearly 320mg/m³ and maximum respirable dust
concentration reaching nearly 283mg/m³. 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 slowly drops with small fluctuations. In the range of 100m~500m dust concentration gradually falls until it stabilizes. In addition, the proportion of respirable dust after blasting is high averaging 79% in the range of 0~50m from the tunnel face and nearly 90% in the range of 100m~500m. 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.

According to the monitoring results, this high altitude tunnel requires some measures to reduce the concentration of harmful gas and dust. Such measures typically fall into two categories: one is to reduce the intensity and total amount of work that produces harmful gas and dust; the other is to mitigate the damage to physical health from harmful gas and dust. The above measures include diffused oxygen supply, spraying water on the tunnel face, water infusion blasting and enhanced ventilation. Based on the harsh construction environment of the high altitude tunnel, water curtain dust reduction and enhanced ventilation are employed to reduce the concentration of harmful gas and dust in this tunnel. CO and dust monitoring data after the measures are taken are presented in Fig. 3 and 4.

![Fig. 3 Distribution of CO concentration near the tunnel face after control measures are taken](image1)

![Fig. 4 Distribution of dust concentration near the tunnel face after control measures are taken](image2)

As shown by the field monitoring data, after water curtain dust reduction and enhanced ventilation measures are taken, CO concentration after blasting is much lower and dust concentration is relatively lower, but the proportion of respirable dust is lowered to an average of 63%. This suggests both CO and dust concentrations near the tunnel face are controlled to some degree but remain high and a hazard to workers. Therefore, workers operating near the blasting site at the tunnel face shall wear dustproof
masks and other protective equipment. Meanwhile, consideration may be given to diffused oxygen supply at the tunnel face and water infusion blasting to reduce the concentration of CO and dust.

5. Conclusions
From study on CO and dust diffusion due to blasting during construction of high altitude tunnels in this paper, the following conclusions can be drawn:

(1) CO concentration within 50m from the tunnel face after blasting is high and the maximum value reaches nearly 330mg/m³; CO concentration close to the tunnel face is much higher than the limiting value.

(2) Dust concentration resulting from blasting is very high, with maximum total dust concentration reaching nearly 320mg/m³ and maximum respirable dust concentration reaching nearly 283mg/m³. 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 slowly drops with small fluctuations.

(3) The proportion of respirable dust after blasting is high averaging 79% in the range of 0~50m from the tunnel face and nearly 90% in the range of 100m~500m.

(4) After water curtain dust reduction and enhanced ventilation measures are taken, CO concentration after blasting is much lower and the proportion of respirable dust is reduced. However, overall CO and dust concentrations remain high and still pose a hazard to workers. Therefore, workers operating near the blasting site at the tunnel face shall wear dustproof masks and other protective equipment. Meanwhile, consideration may be given to diffused oxygen supply at the tunnel face and water infusion blasting to reduce the concentration of CO and dust.

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