A smoke exhausting method through a baffle-coupled shaft during tunnel fires

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Abstract. In natural ventilation of road tunnel shaft, the plug-holing and boundary layer separation will decrease the efficiency. A new concept (baffle-coupled shaft) is put in place to solve the difficulty. Install baffle on both sides of the shaft (when the fire occurs upstream of the shaft, the baffle upstream of the shaft closes and the baffle downstream of the shaft opens), in the early stage of the fire, it can function as a smoke barrier. Numerical simulation was performed using the Fire Dynamic Simulation (Version 5.5.3). We use the mass flow of carbon monoxide discharged through the shaft as a basis for evaluating the efficiency of exhausting smoke. We could have determined that with the height of the baffle increasing, so does the efficiency of exhaust. In the investigation, the height of urban road tunnels is generally about 5 meters. So, it is appropriate to set the baffle height to 2m. Comprehensive car capacity, economy and cold air distributed, we can get a better He, that is in 1.0-1.5.

Keywords: plug-holing, boundary layer separation, baffle-coupled shaft, smoke barriers

1. Introduction

With the intensification of urbanization, urban traffic conditions have become more and more crowded, many tunnels were built in the city to ease the pressure on urban traffic, due to the dual social and economic advantages of shortening the operating mileage, saving vehicle transportation time and reducing irreversible damage to the natural environment, highway tunnels are widely used in the mountainous geographical environment of western China, and the number and length of construction are also rising rapidly[1], especially in Chongqing. Since the death of a tunnel fire is basically caused by smoke, in order to facilitate the evacuation of citizen, an effective smoke exhaust system must be installed in the tunnel. In tunnel fires, the control of fire smoke mainly includes mechanical smoke exhaust and natural smoke exhaust.

There are a few studies about smoke control. Miao Cheng Weng [2] has study smoke control in a metro tunnel with one opening portal. Long-Xing Yu[3] did a series of full-scale experiments and studied smoke control using transverse ventilation in a sloping urban traffic link tunnel fire, and get conclusion that For tunnel with a slope going uphill from upstream to downstream, supplying air from the downstream is recommended while supplying air from the upstream or directly to the fire located smoke compartment should be avoided. Tanaka et al. [4] studied the characteristics of smoke extraction by natural ventilation in a shallow urban road tunnel scale model with roof opening, and a correlation for predicting the smoke height under different heat release rates (HRRs) was developed. H. Y. Cong et al. [5] has put forward a board-coupled shaft. In this paper, a new method will be suggested, that is a baffle-coupled shaft. In this paper, we will discuss the natural ventilation systems. For example, vertical shaft, roof opening, are still a universal method. They get an advance such as stability, economy.
2. Numerical modelling

2.1. Fire dynamics simulator

In tunnels fire, many researcher use FDS (Fire Dynamics Simulator) to verify their guess. FDS is a powerful fire simulator which was developed at the National Institute of Standards and Technology (NIST). And it uses a large-eddy simulation (LES) code for low speed flows, with an emphasis on smoke and heat transport from fires which have already been widely used to investigate tunnel fire. Therefore, FDS was utilized to perform the CFD simulations in the present study. This approach is very flexible and can be applied to fires ranging from stove-tops to oil storage tanks. It can also model situations that do not contain a fire, such as ventilation in buildings. The simulation in this research was used to Fire Dynamic Simulation (Version 5.5.3).

2.2. set-up of simulations

The model was a road tunnel in chongqing, its length, width, and height is 90m, 10m and 5m, as showed in Figure 1. Accord to fang liu[6] research, the sectional coefficient (ζ) is 2.0. the vertical shaft is located 50 meters from the left side of the tunnel. It size is 2.0m(L)*2.0m(W)*7.0m(H). Heptane pool fire was used, the fire source is 20 meters to the left of the shaft, HRR (Heat release rate) is 5.0 MW. The baffle is located two meters to the right of the shaft, and We use He to indicate the height of the baffle height (The height of the blue part in the picture). The scheme of FDS simulations are shown in Table 1.

![Figure 1. the model of simulation](image)

![Table 1. Scheme of FDS simulations.](table)

| Case | HRR (Heat release rate /MW) | Baffle height (He/m) |
|------|-----------------------------|----------------------|
| 1    | 5.0                         | 0                    |
| 2    | 5.0                         | 0.5                  |
| 3    | 5.0                         | 1.0                  |
| 4    | 5.0                         | 1.5                  |
| 5    | 5.0                         | 2.0                  |
2.3. Meshes

The FDS user’s guide suggests that a non-dimensional expression $\frac{D^*}{\delta x}$ can be used to measure how well the fire induced flow field could be resolved, when its value is very good between 4 and 16. where $D^*$ is a characteristic fire diameter (m) and $\delta x$ is the nominal size of a mesh cell (m).

\[ D^* = \left( \frac{Q}{\rho_c p T_a g} \right)^{2/5} \]  

Before start simulation, we conducted three different mesh size ($0.25D^*$, $0.1D^*$, $0.625D^*$), has find that when $\delta x$ is $0.1D^*$ is better. It not only can save time, but also has high precision. So in this study, the mesh sizes are set as $0.1D^*$.

3. Results and discussions

Figure 2 shows the ceiling temperature. Obviously, we can find that reaches the stable period during 100-200 s and all parameters were calculated within this stage. About He=2.0m, a reasonable explanation is that higher baffles prevent the smoke from spreading downstream, resulting in very low mass flow of it at the outlet.

Figure 2. Ceiling temperatures at the right end of the tunnel under different He.

Figure 3. Parameters related to smoke extraction efficiency
3.1. Comparison between the baffle-couple and tradition shaft

From Figure 4 and Figure 5, we can find plug-holing will disappear under the action of the baffle. Smoke moves toward the baffle, and returns after encountering the obstruction.

![Figure 4](image1.png)\(\text{Figure 4. Temperature distribution in the tunnel and shaft}\)

![Figure 5](image2.png)\(\text{Figure 5. Velocity distribution in the tunnel and shaft}\)

3.2. Effects of baffle height on the baffle-coupled shaft

He=0, 0.5, 1.0, 1.5, 2.0 m were researched for the effect of He on the exhaust of the baffle-coupled shaft.

In this paper, smoke exhausted from shaft is think as mixed gas, so, the CO extraction mass flow \(M_{co}\) is chosen as parameter to evaluate smoke extraction capacity, and can be described as[5]

\[
M_{co} = W_s \times M_s
\]
(a) $He=0.5$

(b) $He=1.0$

(c) $He=1.5$

(d) $He=2.0$

Figure 6. Temperature distribution with different $He$
Temperature and velocity distributions are show in Figure 6 and Figure 7. Cold air (ambient temperature is 20 °C, so we can define air below 40 °C as cold air) can still flow into the shaft if He is relatively small. And this phenomenon would disappear as the baffle becomes higher. From Figure 3. We can find that $M_{co}$ (CO mass flow) is increasing with the He. This trend can be divided into three periods. When He is in 0-0.5 and 1.5-2.0, $M_{co}$ growth is very slow. However, in 0.5-1.5, it become very fast. Comprehensive Vehicle capacity, economy and cold air distributed, we can get a better He, that is in 1.0-1.5.

4. Conclusion

Based on the simulated results, we can get the following conclusions.

(1) the baffle-coupled shaft is better than the traditional shaft, apart from this, plug-holing can also be eliminated using a baffle-coupled shaft

(2) He is not higher the better, car capacity, economy and cold air distributed, we can get a better one.

Future work will focus on the effect of the spacing between the baffle and the shaft, baffle width.

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