Influence of a Baffle and Shaft Spacing on Shaft Exhaust Efficiency

Hou QianKun¹, Miao-cheng Weng¹ and Fang liu¹

¹ School of civil Engineering, Chongqing University, China
Email: godlovekoh@outlook.com

Abstract. In road tunnel. A baffle-coupled shaft is used to decrease the plug-holing and boundary layer separation. 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), it can function as a smoke barrier. In order to study the distance between the baffle and shaft, numerical simulation was performed using the Fire Dynamic Simulation (Version 6.7.1). We use the mass flow of carbon monoxide discharged through the shaft as a basis for evaluating the efficiency of exhausting smoke. As the spacing increases, the exhaust efficiency increases first and then decreases. In this paper, the baffle-coupled is set 2 meters.

1. Introduction
In road tunnel, there are two main ways of ventilation and exhaust of tunnels, namely natural smoke exhaust and mechanical smoke exhaust. Among them, the shaft smoke exhaust is part of natural smoke exhaust, which is setting a ventilation shaft directly connected to the air at a certain distance from the top of the tunnel. When the fire is caused, the piston wind generated by the vehicle driving during normal driving causes the exhaust gas to be discharged through the shaft.

Yanfu Wang[1, 2] conducted a set of experiments in a full-scale tunnel with roof open, tested the effect of natural smoke exhaust and investigated the backflow distance; Jie ji[3] has studied the shaft geometry in road tunnel fires and gained that for lower shafts, the advantage of using the bevel-angle connection is more significant, and for shafts of the same height, the mass flow rate of smoke discharged by shafts with the bevel-angle connection increases up to 1.5 times of that by shafts with the right-angle connection. For relatively high shafts, it is about 1.2 times; Cong H,Y [4] has pointed the new way for shaft smoke exhaust, his called board-coupled; Vauquelin studied the influence of location and shape of the shaft on the exhaust efficiency. Fan investigated the effect of shaft arrangement on natural ventilation performance, and indicated that the total mass flow rate of smoke exhausted increases with the shaft amount as the total area of shafts is given; Tong Yan [5] conducted full-scale burning tests in a road tunnel with natural ventilation using shafts and found that large amounts of smoke and heat were released through shafts. Huang Yuan-dong[6] numerically simulated the effect of the ventilation shaft arrangement and geometry on natural ventilation performance in a subway tunnel. In this paper, we set a series of simulations to conduct the distance between a baffle and shaft.

2. Numerical modelling

2.1. Fire dynamics simulator
In tunnel fire, researchers use Fire Dynamic Simulation (FDS) to confirm their conjecture. FDS simulates fire scenarios using computational fluid dynamics (CFD) optimized for low-speed, thermally-driven flow. 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 include a fire, such as ventilation in buildings. So, the simulation in this paper was used to Fire Dynamic Simulation (Version 6.7.1).

2.2. Set-up of simulations

The model is a road tunnel in Chongqing, China. Its length is 90m, width is 10m, and the height is 5m, as showed in Figure 1. the vertical shaft is located 50 meters from the left side of the tunnel. Its size is 1.6m (L)×1.6m (W)×7.0m (H). Heptane was used as fuel, is 20 meters to the left of the shaft, fire source power (HRR) is 5.0MW. The baffle height is 2.0 meters to the right of the shaft, and the distance between the baffle and shaft is variable, we can use D instead of the distance. For example, the D=0 is mean that there is not baffle. The scheme of FDS simulations are shown in Table 1.

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

| Case | HRR(MW) | the distance between the baffle and shaft (D) |
|------|---------|----------------------------------|
| 1    | 5.0     | 0                                |
| 2    | 5.0     | 0.8                              |
| 3    | 5.0     | 2.0                              |
| 4    | 5.0     | 3.0                              |
| 5    | 5.0     | 5.0                              |
| 6    | 5.0     | 6.0                              |
| 7    | 5.0     | 8.0                              |
| 8    | 5.0     | 10.0                             |

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).

\[
D^* = \left( \frac{q}{\rho_a C_{p,a} S_{1/2}} \right)^{1/5}
\]

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

Figure 2. shows the ceiling temperature. From this picture, we can find that reaches the stable period within 150-250s and all parameters were calculated within this stage. Except for D=0, all the rest case ceiling temperature at the right end of the tunnel less than 30 °C. A reasonable explanation is that higher baffles prevent the smoke from spreading downstream, resulting in very low mass flow of it at the outlet.

3.1 Effects of a baffle and shaft spacing on the baffle-coupled shaft

In this paper, smoke exhausted from shaft is think as diluted gas, so, the CO extraction mass flow $M_{co}$ is chosen as parameter to evaluate smoke extraction capacity, and can be described as[7]

$$M_{co} = W_s \cdot M_s$$  \hspace{1cm} (2)

From Figure 3, we can find that when D is equal to 5 is best. It can extract more CO, mean that it has more extraction efficiency.

In order to reflect the influence of the distance of the baffle on the smoke exhaust, we show the temperature and speed clouds when D=0, 3, 5, 8m.

From Figure 4. We can find that a baffle plays an important role in decreasing plug-holding, when D=0, cold air (ambient temperature is 20 °C, so we can define air below 40 °C as cold air) enters the shaft. This phenomenon we called plug-holding. For other case, smoke is controlled between the baffle and the shaft.
Figure 3. Parameters related to smoke extraction efficiency

Figure 4. Temperature distribution with different D
4. Conclusion
According to the simulated results, we can get the following conclusions.
1) The baffle-coupled shaft can significantly improve the efficiency of smoke exhaust.
2) The baffle-coupled shaft plays an important role in reducing the temperature of the downstream smoke layer and controls the smoke in a certain area.
3) When the baffle height is 2.0 meters. The D is not the bigger the better. When D=5.0 m, it has more efficiency of smoke exhaust.

5. References
[1] Wang YF, Jiang JC, Zhu DZ, Diesel oil pool fire characteristic under natural ventilation conditions in tunnels with roof openings, Journal Of Hazardous Materials, 2009;166: 469-77.
[2] Wang Y, Jiang J, Zhu D, Full-scale experiment research and theoretical study for fires in tunnels with roof openings, Fire Safety Journal, 2009;44: 339-48.
[3] Ji J, Fan CG, Gao ZH, Sun JH, Effects of Vertical Shaft Geometry on Natural Ventilation in Urban Road Tunnel Fires, Journal Of Civil Engineering And Management, 2014;20: 466-76.
[4] Cong HY, Wang XS, Zhu P, Jiang TH, Shi XJ, Experimental study of the influences of board size and position on smoke extraction efficiency by natural ventilation through a board-coupled shaft during tunnel fires, Applied Thermal Engineering, 2018;128: 614-24.
[5] Tong Y, Shi MH, Gong YF, He JP, Full-scale experimental study on smoke flow in natural ventilation road tunnel fires with shafts, Tunnelling and Underground Space Technology, 2009;24: 627-33.
[6] Huang YD, Gong XL, Peng YJ, Lin XY, Chang-Nyung K, Effects of the ventilation duct arrangement and duct geometry on ventilation performance in a subway tunnel, Tunnelling and Underground Space Technology, 2011;26: 725-33.
[7] Cong HY, Wang XS, Zhu P, Jiang TH, Shi XJ, Improvement in smoke extraction efficiency by natural ventilation through a board-coupled shaft during tunnel fires, Applied Thermal Engineering, 2017;118: 127-37.