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Simulation analysis on the influence of smoke flow in special section tunnel under mechanical ventilation

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Abstract. In this study, a special section tunnel model was established by using FDS (Fire Dynamics Simulator). In the condition of mechanical ventilation, studied the effect of the model for exhaust velocity interval and curvature, slope on the smoke flow. Finally, the longitudinal wind speed of 3m/s is determined, and the results show that the curvature and slope of the tunnel have no effect on the smoke flow.

1. Introduce Fds Software
The fire dynamics simulation software FDS is a computational fluid dynamics model of a fire to drive, it is calculated using the Navier-Stokes equations, the equation for calculating the heat flux, low speed driving, especially the flue gas flow and heat transfer in case of fire, the core algorithm is to establish a clear predictor corrector system to ensure the accuracy of both in terms of time and space.

In dealing with the problem of turbulence, FDS uses a large eddy simulation (LES, Large Eddy Simulation), LES is also its default calculation model. At present, FDS has solved many fire problems in fire engineering, and proved to have a strong ability to restore.

At the same time, FDS software uses Smokeview visualization program to display the results of fire dynamics simulation.

2. Establishment of a Model of Special Section Tunnel

2.1 Tables
This paper relied on the project for the Hong Kong-Zhuhai-Macao bridge’s connecting line of Gongbei tunnel, the tunnel is divided into three sections of the open cut section of the sea, the port and the excavation section of the excavation section. The plane of the tunnel is composed of a straight line, a transition curve and a circular curve, showing the "W" type. The longitudinal section from 2.412% downhill to the gentle slope of 0.35% to the slope of 2.995%, was "U" type. The minimum curve radius of the road is 890m, the maximum longitudinal slope is 2.995%, and the minimum longitudinal slope is 0.35%. Plane graph of Gongbei tunnel is shown in Figure 1. Longitudinal section of Gongbei tunnel is shown in Figure 2.
2.2 The Establishment of Calculation Model
According to the actual size of Gongbei tunnel, a simulation model is established which is shown in Figure 3. The physical model is selected from the pile number YK1+467.696 to YK3+582 segment, and the total length is 2114.304m.

In addition, it is also an important step in the simulation process of FDS to divide the simulation computing area into the computational grid (Meshes), which directly affects the accuracy of the calculation results. The small size of the grid can improve the accuracy, but it will slow down the simulation speed and increase the calculation time. The large grid size can improve the simulation speed, but it will reduce the accuracy of the simulation. Therefore, considering the factors such as model size, computer configuration and the accuracy of calculation results, the mesh size in numerical simulation is 0.5m * 0.5m * 1m. The computational mesh is shown in Figure 4.

In the process of designing the fire scene, the fire source is located in the building on the premise of taking full account of the geometric characteristics of the building. To ensure the accuracy of the fire location, it is necessary to take into account the possible scale of fire, the spatial characteristics of each functional area within the building, the distribution of evacuation exit and smoke control measures. In addition, the slope and curvature of the tunnel should be considered. Based on the above factors, 5 fire
sources are located in the right line of the tunnel. The location of fire is shown in Table 1. Schematic diagram of fire source location is shown in Figure 5.

| number | The location of fire | Height difference | Slope  | curvature |
|--------|----------------------|------------------|--------|-----------|
| B      | HJD-35               | 11.083           | -2.412%| 1.22%     |
| E      | middle section       | -1.566           | 0.350% | 0.96%     |
| F      | LJD-08               | -1.874           | 0.350% | 0.47%     |
| G      | LJD-21               | -5.469           | 0.350% | 1.39%     |
| H      | LJD-35               | -10.412          | 2.995% | 1.13%     |

Figure 5: Schematic diagram of fire source location

In order to approach the actual situation, super-fast fire is selected, which fire growth rate is 0.1875 kW/s², the heat release rate is 50MW, and the combustion time is 516s. The plate size is 3m* m according to the grid precision and calculation model.

3. Simulation result analysis

3.1 Study on wind speed of mechanical ventilation

The local model numerical calculation as an example, discusses the different longitudinal velocity of flue gas reflux suppression effect. The simulation results when the flue gas recirculation is stable are shown in Figure 6. The simulation results show that the flue gas recirculation can be controlled effectively when the wind speed is greater than 3m/s.

Figure 6: Recirculation length under different wind speeds

Smoke control to avoid the removal of flue gas recirculation factors, should also consider the downstream visibility problem. So, set the 10m visibility equivalent surface for observation. Figure 7 shows the influence of different longitudinal wind speeds on the 10m visibility equivalent surface. It can be seen from the figure, with the increase of the longitudinal velocity, tunnel downstream 10m visibility in the isosurface is more disorder. Increasing the longitudinal wind speed to 4m/s can effectively control the flue gas recirculation, but with the increase of wind speed, the lower of the smoke layer is faster, and the 10m visibility is more chaotic. This is not conducive to the downstream vehicle to escape.
Figure 7: 10m visibility equivalent surface

According to the results of the small size model, the longitudinal wind velocity of 3m/s and 4m/s is simulated in the 1:1 prototype. The results are shown in Figure 8. Among them, the case of 3m/s using 600s, the case of 4m/s using 650s.

Through the above comparison, we can see that although the wind speed of 4m/s is more conducive to the upper reaches of the evacuation than 3m/s, but the lower’s speed of spread of flue gas improve larger, which is not conducive to the vehicle in downstream to escape. Considering the longitudinal wind speed is 3m/s~4m/s, this paper selects 3m/s.

3.2 Influence of slope on flue gas flow under mechanical ventilation

Three different slope calculation conditions were selected and compared in order to study the influence of slope on the smoke flow. The slope is different but the curvature is similar. Other conditions on the effects of smoke flow are ignored. Selection of fire scene under mechanical ventilation is shown in Table 2.

| number | Heat release rate (MW) | Slope | Longitudinal wind velocity (m/s) |
|--------|------------------------|-------|---------------------------------|
| B3     | 50                     | -2.412% | 3                               |
| G3     | 50                     | 0.350%  | 3                               |
| H3     | 50                     | 2.995%  | 3                               |

When the fire source is located at -2.412%, 0.350% and 2.995% degrees of slope, the smoke spread under the condition of mechanical ventilation is as follows.

Figure 9: Fire scene B3(-2.412%)
As can be seen from the above figures, the effect of slope on the smoke flow can be ignored under the 3m/s wind speed.

3.3 Influence of curvature on flue gas flow under mechanical ventilation

Three different slope calculation conditions were selected and compared in order to study the influence of curvature on the smoke flow. The curvature is different and the slope is similar. Other conditions on the effects of smoke flow are ignored. Selection of fire scene under mechanical ventilation is shown in Table 3.

| number | Heat release rate | curvature | Longitudinal wind velocity (m/s) |
|--------|------------------|-----------|---------------------------------|
| E3     | 50               | 0.96%     | 3                               |
| F3     | 50               | 0.47%     | 3                               |
| G3     | 50               | 1.39%     | 3                               |

When the fire source is located at 0.96%, 0.47% and 1.39% degrees of curvature, the smoke spread under the condition of mechanical ventilation is as follows.
As can be seen from the above figures, the effect of curvature on the smoke flow can be ignored under the 3m/s wind speed.

4. Conclusions
In this study, a special section tunnel was established by using FDS (Fire Dynamics Simulator). The influences of lope and curvature on smoke flow under mechanical ventilation have been studied. The results showed that:

(1) Under the condition of mechanical ventilation, the slope has some influences on the smoke flow in special section tunnel. Smoke spread along the tunnel sides are no longer symmetrical due to the existence of the slope. The smoke spreading speed is accelerated along the upstream direction and down along the downstream direction due to buoyancy effect of slope. The steeper the tunnel is, the more obvious the buoyancy effect is.

(2) Comparing with the spread rate of flue gas under different curvature, it can be seen that, the curvature has little effect on the flow of flue gas.

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