Electronic supplementary materials

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Effects of the jet fan air velocity response strategy and fire source location on the immersed tunnel fire smoke control

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S1: Control equations

The main control equations related to FDS are as follows:

Mass conservation equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \boldsymbol{u} = \dot{m}_b''' \tag{S1}$$

where ρ is the ambient air density, kg/m^3; $\boldsymbol{u}$ is the velocity vector, m/s; t is the simulation time, s; $\dot{m}_b'''$ is the mass productivity per unit volume, kg/(m^3 s).

Momentum conservation equation:

$$\frac{\partial}{\partial t}(\rho \boldsymbol{u}) + \nabla \cdot \rho \boldsymbol{u}\boldsymbol{u} + \nabla p = \rho g + \boldsymbol{f}_b + \nabla \cdot \tau_{ij} \tag{S2}$$

where g is the acceleration of gravity, m/s^2; $\boldsymbol{f}_b$ is the external force acting on the fluid except gravity, kg/(m^2 s^2); τ_{ij} is the viscous force tensor, kg/(m s^2); p is the pressure, Pa.

Energy conservation equation:

$$\frac{\partial}{\partial t}(\rho h) + \nabla \cdot \rho h \boldsymbol{u} = \frac{Dp}{Dt} + q''' - q_b''' - \nabla \cdot q'' + \varepsilon \tag{S3}$$

where h is enthalpy, kJ/kg; q''' is the heat release rate per unit volume, kW/m^3; q_b''' is the energy transferred to the evaporated droplet, kW/m^3; q'' is the heat flux vector, W/m^2; ε is the dissipation rate, W/m^3.

S2: Heat transfer process

Conduction, convection and radiation processes occur during tunnel fires. For example, hot air rises after a fire, while cooler air falls, creating convective flow. The fire releases a large amount of thermal radiant energy, and the radiant energy is transmitted in the form of electromagnetic waves that directly heat other surfaces in the tunnel. Tunnel walls near the source of fire may transfer heat through thermal conductivity to wall sections away from the source of fire due to high temperatures. Radiation, convection and conduction models were considered for simulations using FDS. Radiative heat transfer is achieved by solving the radiative transfer equation for gray gases and, in some limited cases, using a broadband model. The equation is solved using a technique similar to the finite volume method for convective transport, hence the name finite volume method (FVM). For convective heat transfer, FDS mainly uses LES to simulate the convective transfer of heat and smoke in air. Larger flow structures can be captured, while smaller flow structures are handled by Subgrid-Scale Models (SSM). In convective modeling, the simulation of heat transfer not only relies on the simulation of air flow, but also involves the computation of turbulent diffusion and turbulent convection, which are achieved by solving the equations of motion and energy equations. The heat conduction model in FDS uses the finite difference method to solve the heat conduction equations inside a solid. The model is able to take into account the physical properties of different materials such as thermal conductivity, density and specific heat capacity in order to calculate the temperature distribution and heat flow in solid materials under fire conditions.

S3: Specific design conditions

Table S1 Test conditions.

Case No.	Fire location (m)	Fan exhaust velocity (m/s)	
		V_{near}	V_{far}
1	70	+20	-30
2	70	+25	-30
3	70	+30	-30
4	70	+35	-30
5	70	+40	-30
6	85	+20	-30
7	85	+25	-30
8	85	+30	-30
9	85	+35	-30
10	85	+40	-30
11	100	-20	+30
12	100	-25	+30
13	100	-30	+30
14	100	-35	+30
15	100	-40	+30
16	115	-20	+30
17	115	-25	+30
18	115	-30	+30
19	115	-35	+30
20	115	-40	+30
21	130	-20	+30
22	130	-25	+30
23	130	-30	+30
24	130	-35	+30
25	130	-40	+30

S4: Schematic diagrams of the near-side and far-side smoke vents

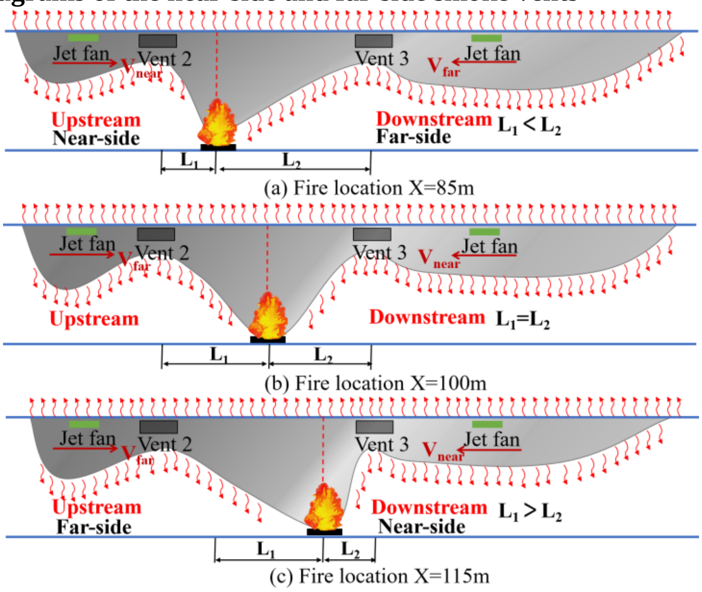

Fig. S1 Schematic diagram of the near-side and far-side of the smoke vent.

S5: Computational domain specification

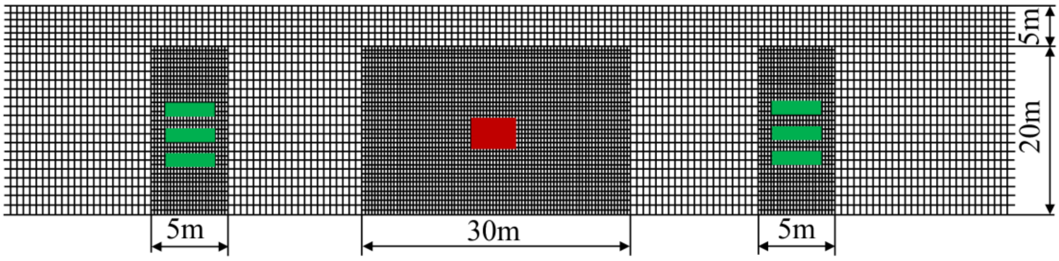

Fig. S2 Grid illustration.

S6: Scale model experimental validation

The scale model immersed tube tunnel is shown in Fig.S3. The longitudinal spacing of the temperature measurement points of the validation model and the distance from the ceiling are also identical to the experimental setup of the model tunnel. The experimental conditions with a longitudinal velocity of 0.5 m/s and a heat release rate of 57.4 kW were randomly selected for experimental validation. A comparison of the numerical simulation results and the reduced-scale model experimental results is shown in Fig.S4. As can be seen in Fig.S4, the simulated values of the tunnel ceiling temperature and the experimental test values of the reduced-scale model basically match, which indicates that the characteristics of the smoke temperature distribution in the extra-wide section immersed tunnel can be very close to the actual smoke temperature distribution, indicating that the numerical simulation method is reliable.

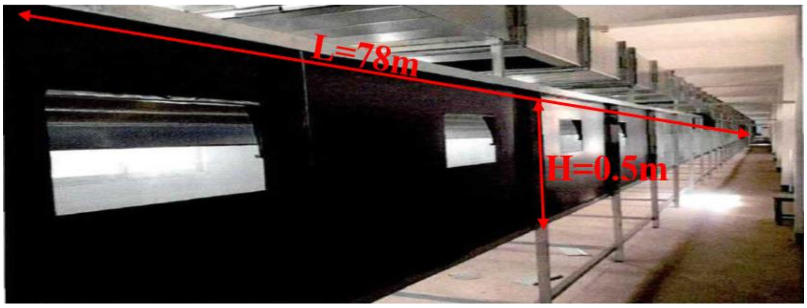

Fig. S3 Model tunnel experiment system.

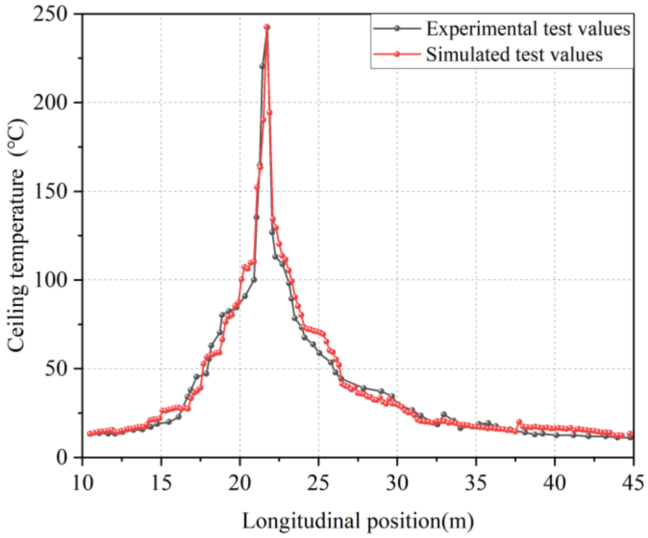

Fig. S4 Comparison of experimental test values and simulated test values.

S7: Smoke spreading process

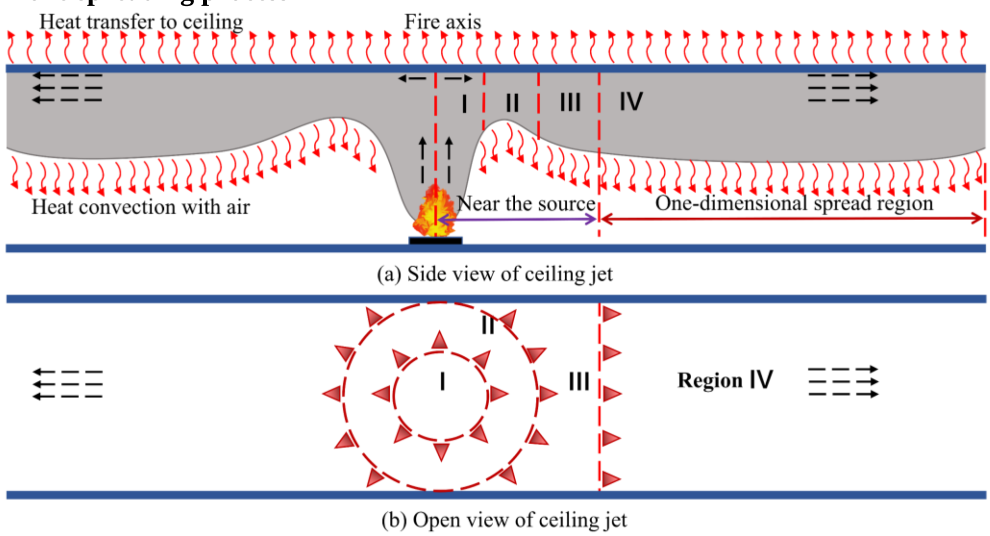

Fig. S5 Tunnel smoke flow diagram.