THE FLOW PROCESS OF SMOKE IN UNDERGROUND BUILDING FIRE

Ye Ruibiao, Ye Mingsheng, Xu Xuqin, Pan Guanxin, Qian Jihu

(Shanghai Fire Research Institute of Ministry of Public Security, Shanghai, China, 200032)

ABSTRACT

This paper describes a smoke flow model which is based on the construction parameters of underground buildings and the thermophysical peculiarities of combustibles and shows the results including the rate of smoke spread from the fire room to corridor, temperature and optical density as a function of time, compares the model results with data from a full scale simulated underground building fire.

INTRODUCTION

Recently underground buildings have been used as markets,public places of entertainment,hotels,classrooms and warehouses in 197 cities of our country.Total area is about 10 million m^2. In Shanghai there are about 1300 thousand m^2.In Beijing there are more than 500 underground hotels with 40 thousand beds.In these buildings there are concentration of a lot people and combustibles, but only fewer exits, fire extinguishing equipments and vents,so that the self-rescue ability is low.In case of fire, a large amount of hot smoke can not be exhausted.Because of the obscuration of smoke,the visibility is decreased seriously,besides the toxicity and high temperature of smoke cause tremendous difficulties in evacuating, extinguishing and rescuing.

So it is an urgent need to study the characteristics of smoke flow in underground building fire,to develop the applicable mathematic model and the computational software.

In view of fire extinguishing and rescuing,this paper discusses the general rule of smoke flow in underground buildings, in consideration of the special construction features,calculates parameters including smoke temperature ,the height of smoke layer and the optical density in the fire room and the corridor.These results are compared with experiment data.

These experiment data quoted in this paper are collected from a full-scale simulated fire of a underground building in Shanghai.The construction and the room facilities are simulated the typical underground hotels at present.There is a 42 m long corridor,two exits to ground at the both terminals. There are rooms at both sides of corridor. There is a air inlet for mechanical ventilation in the room. Total area of the underground building is 305 m^2 and the area of the fire room is 22 m^2. See Fig.1.

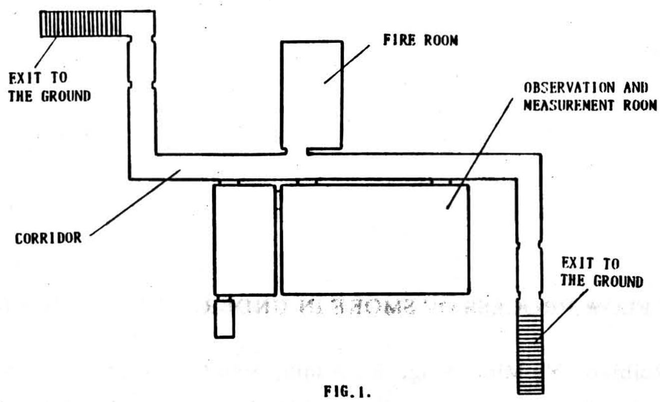

FIG.1.

FLOW CHARACTERISTIC OF SMOKE

1. The Time Smoke Beginning to Emit From a Room of Fire Origin

A room in underground building for civil use has no connecting passage other than doors,windows joining with corridors. So smoke would soon emit from an opened door and rush into a corridors in case of fire.

Thomas (1984)[1] suggested the fllowing equation to calculate the time smoke begining to emit from a room:

$$t = bA(\rho C_p T_a / g \dot{Q})^{1/3} (1/h^{2/3} - 1/H^{2/3}) \quad (1)$$

where b = constant,
A = floor area of the room,
T_a = temperature of environmental air,
ρ = density,
C_p = specific heat,
g = acceleration of gravity,
$\dot{Q}$ = rate of heat release,
h = height from floor to upper brim of the door,
H = height of the room.

Zukoski (1985)[2] suggested the following corresponding equation:

$$\dot{H}^* + \dot{Q}^* + \alpha (Q^*)^{1/3} H^{*5/3} = 0 \quad (2)$$

where H^* = relative height of lower interface of the smoke layer,
$\dot{Q}^*$ = relative heat release rate,
α = the mass entrainment coefficient.

Calculation shows that a value more approaching to the experimental result can be obtained by the Mccofforoy equation adopted by the FAST model.[3] Its equation expressed as following:

$$\dot{m}_g = K Q (Z_g / Q^{\lambda})^{\mu} \quad (3)$$

where $\dot{m}_g$ = rate of smoke mass generation,
Z_g = thickness of smoke layer,
k, λ, μ are experic coefficients respectively.

Then the time for the lower interface of the smoke layer to reach the upper brim of the door, namely the time smoke begining to emit the room can be obtained by

$$t = A Z_1 \rho_g / \dot{m}_g \quad (4)$$

where Z_1 = the vertical distance between the upper brim of the door and the ceiling,

ρ_s = smoke density.

It is pointed out by the experimental report[4] that the time from a fire occured to smoke emitting from the room is less then 30 s in some experiments.

2. Corridor Smoke Transfer Rate

The continuous equation of the horizontal flow of smoke in corridor is as below:

$$\dot{m}_g = \rho_g B Z_g V \tag{5}$$

where B = width of corridor,

V = horrizontal transfer rate of smoke along the corridor.

The relation of the thickness of smoke layer to horrizontal flow velocity can be derived[5] from buoyant characteristic of smoke:

$$(\rho_a - \rho_g)\, g\, Z_g = \zeta \rho_g V^2 / 2 \tag{6}$$

ρ_a = density of environmental air,

ζ = coefficient.

Following equations can be derived from (5) and (6):

$$V_g = K_1 \dot{m}_g^{1/3} \rho_g^{-1/3} (\theta - 1)^{1/3} \tag{7}$$

$$Z_g = k_2 \dot{m}_g^{2/3} \rho_g^{-2/3} (\theta - 1)^{-1/3} \tag{8}$$

Where $K_1 = (\zeta B / 2g)^{-1/3}$, $K_2 = (\zeta / 2g B^2)^{1/3}$, $\theta = T_g / T_a$,

T_g = average temperature of the smoke.

Equations (7) and (8) indicate that both the transfer rate of smoke along the corridor and the desending rate of lower interface of the smoke are relatively quick due to the narrowness of the corridor in the underground building for civil use.

As pointed out in the experimental report , the transfer rate of smoke soon after a fire occured is about 0.5 m/s, if there is a wind in the corridor, the transfer rate in the direction of the wind will be quciker. The descending rate of the lower interface of the smoke layer is about 12 cm/min.

3. The Smoke Density in the Underground Building for Civil Use

Once a fire occured in an underground building of civil use, thick smoke would be generated from combustion of wooden furniture and fibre, and cause shape descending of visibility in the building.

Smoke density is usually expressed as optical density. Optical density and visibility are given as:

$$D / L = \alpha_p X_p \dot{m}_f / \dot{V} \tag{9}$$

$$L_v = K_v / (D / L) \tag{10}$$

where D = the optical density of the smoke,

L = the metrical length of the beam,

α_p = the optical density of the smoke particles,

m_f = the combustion loss of the fuel mass,

χ_p = the ratio of the generation rate of the smoke particles mass to the combustion loss of the fuel mass,

$\dot{V}$ = the volumetrical flow of the smoke,

L_v = visibility,

K_v = coefficient.

The volumetrical flow of the smoke can be derived from the following equation:

$$\dot{V} = (\dot{m}_a + \dot{m}_R + \dot{m}_f)\, T_g / \alpha_a \qquad (11)$$

where $\dot{m}_a$ = flow of air mass entrained in the smoke,
$\dot{m}_R$ = flow of air mass taking part in combustion reaction,
α_a = coefficient.

Substitute equation (11) into equation (9) and (10), the equation of optical density and visibility can be obtained:

$$D = \alpha \beta_f / (1+\beta_a)\, T_g \qquad (12)$$

$$L_v = k \beta_f^{-1} (1 + \beta_a)\, T_g \qquad (13)$$

where $\alpha = L \alpha_a \alpha_p X_p$, $\beta_a = \dot{m}_a / \dot{m}_g$, $\beta_f = \dot{m}_f / \dot{m}_g$,
$k = k_v / \alpha_a \alpha_p X_p$.

Fig.7. is a time history plot for the visibility of a place 1.5 m from the floor of the corridor messured in the experiment.

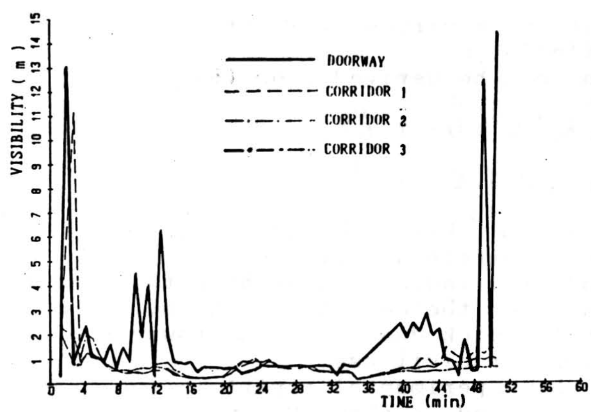

FIG. 2.

MATHEMATICAL MODEL DISCUSSION

Because of the capacity of the computer used in Chinese Fire Brigades and in order to shorten the calculation time, this paper use the zone modeling method.

According to the basic equation and auxiliary equation, We can set the following mathematical model of the smoke temperature, the smoke height and the smoke density in the corridor.

Equation of thickness of smoke layer

$$z_g = k_2 \dot{m}_g^{2/3} \rho^{-2/3} (\theta - 1)^{-1/3}$$

Equation of variation of smoke layer temperature

$$\Delta T_g = -\dot{Q}_L / \dot{m}_g C_p (1 + \beta_a) - T_a \beta_a (\theta - 1)/(1 + \beta_a) \qquad (14)$$

Where $\dot{Q}_L$ = Total heat loss rate

Equation of optical density

$$D = \alpha \beta_f / (1 + \beta_a)\, T_g \qquad (15)$$

In this model, we introduce the geometric condition, the physical condition, the original condition, and the boundary condition, that fit the underground building and solve it with numerical method.

In this mathematical model, considering mechanical ventilation in the room, the smoke entrainment force in the corridor, the partial condition in the corridor when smoke removing, we revise the zone modeling method in some aspect,we also suppose the wind has a regular rate in the corridor when venting smoke,the air flow for the smoke venting is mixed fully with the smoke in the corridor.

CONCLUSION

The computer software programed by use of the mathematical model can predict the fire condition of underground building for civil use quickly and quantitatively, that can provide scientific basis for preparing the prefire plannings, revising the fire prevention codes for underground building, and for improving the fire safety management of underground building.

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