A SMOKE CONTROL CALCULATION FOR PRESSURIZED ELEVATOR SHAFT

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1. INTRODUCTION

The possibility of using pressurized elevator for the evacuation of the handicapped is being explored by Klote, Tamura and others[1]. In this paper, it is shown that the computer smoke transport model developed by the author et al.[4] is successfully applicable for the case where a building has a shaft with a moving cage, and the effects of multiple air supply inlets on the smoke control of pressurized elevator shaft are investigated.

2. MATHEMATICAL FORMULATION

Klote and Tamura made the experiments and theoretical analyses on the air flow in a pressurized elevator shaft with a moving cage[2,3], however, it will be difficult to apply their analytical method to the conditions which change as a fire develops in a building. The advantage of using a computer model is that it can be flexibly applied to such transient conditions. Unlike usual one zone models for smoke transport in buildings, the change of node(space) volume with respect to time cannot be ignored when a cage moves in a shaft. Accordingly, the basic equations for the smoke transport in a building are given as follows:

(1) Mass conservation

$$\{V\frac{d\rho}{dt}\}+\{\rho\frac{dV}{dt}\}+[I]\{w\}=\{W\} \qquad (1)$$

where V,ρ,w and W stand for node volume[m^3], gas density[kg/m^3], net flow rate at opening[kg/s] and mass generation rate[kg/s], respectively. Symbols {} stand for vector of nodes and {} stand for vector of openings, and [I] is the incidence matrix[4]. Note that $dV/dt\neq0$ at a node in the elevator shaft when the cage is moving in the node.

(2) Energy conservation

$$\{C_p\frac{\rho TV}{P}\frac{dP}{dt}\}+\{C_p\rho T\frac{dV}{dt}\}+[I]\{E\}=\{Q\} \qquad (2)$$

where C_p,P,T,E and Q stand for specific heat of gas [kJ/kgK], absolute pressure[Pa], temperature [K], net energy flow at an opening[kJ/s] and heat release rate[kW], respectively. When temperature is the same at all the nodes, Equation (2) becomes as follows:

$$\{C_p\rho T\frac{dV}{dt}\}+C_pT[I]\{w\}=\{Q\} \qquad (2')$$

(3) Equation of state of ideal gas

$$P=\rho RT \qquad (3)$$

(4) Flow rate through an opening

Flow rate through an opening is calculated using Bernoulli's equation for orifice flow as a function of pressure difference, temperature and opening conditions.

(5) Change of node volume

The difference of this system of equations from that of existing one is that dV/dt term is added in the equations for mass and energy conservations. The change of the volume with time of a node in which an elevator cage is passing is given as

$$\frac{dV}{dt}=A_c v \qquad (4)$$

where A_c and v stand for the horizontal section area [m^2] and the velocity of the cage [m], respectively.

3.CALCULATION OF SMOKE CONTROL IN THE ELEVATOR SHAFT

The experiments by Klote et al.[3] were conducted under room temperature condition. For the smoke transport calculation at constant temperatures, Eqns. (2'),(3) and (4) are the only equations to be used.

The test building is modeled as shown by the graph in Figure 1. The input property data are given in Table 1. The velocity of the elevator cage is modeled as shown in Figure 2.

In this calculation method, the elevator shaft is divided at each floor height so that each segment space is taken as a node. The pressure loss ΔP due to flow friction of the elevator shaft can be calculated by the following equation, which has been established for circular ducts.

$$\Delta P=\lambda(L/D)\ v^2/2 \qquad (5)$$

where λ,L,D stand for friction coefficient, length [m] and diameter of the duct [m], respectively. Substituting the real dimensions of the shaft in the experiment by Klote and Tamura into D and L, and an established data for concrete duct into λ, we have the value corresponding to the flow coefficient for the length of a floor height as follows:

$$(D/\lambda L)^{1/2}=5.0 \qquad (6)$$

As for the flow coefficient α' for the space between the cage and the shaft wall, Klote et al. obtained the value of 0.83. The value of α' was calculated using the following equation assuming that the volume flow rate through the space is equal to the shaft section area multiplied by the cage velocity.

$$A_s v=\alpha' A_f(\rho\Delta P/2)^{1/2} \qquad (7)$$

where A_s and A_f stand for the section area of the shaft and the space between the shaft wall and the cage, respectively.

On the other hand, in this calculation method, it is considered to be more appropriate to use the cage section area A_c instead of A_s in Eq.(7) for defining the flow coefficient α, then using the data of Klote's experiment, α becomes as follows.

$$\alpha=\alpha' A_c/A_s=0.6 \qquad (8)$$

In Figure 3, comparisons of the pressure between the analysis by Klote et al. and this computing method are shown. A good agreement is seen between the two in case of α=0.6.

The comparison of the pressure between the experiments by Klote and Tamura for a pressurized elevator shaft with a moving cage and the results of the calculations by the computer smoke transport model are shown in Figure 4 and 5 respectively for the cases, when the cage ascends and in Figure 5 when the cage descends. These results show a good agreement between the experiments and the calculations.

4.EFFECT OF AIR SUPPLY PATTERNS ON SHAFT PRESSURE

In order to investigate the effects of different air supply patterns on the smoke control efficacy of a pressurized elevator shaft, the calculations were made for the following three typical supply patterns.

(1) air supply at two positions; on the 1st and the 15th floors
(2) air supply at three positions; on the 1st,8th and 15th floors
(3) uniform air supply; on each of the floors

The total air supply rate is fixed at the same value which is uniformly distributed to the air supply positions in each case.

The calculation results of pressure at the levels of 1st, 8th and 15th floors in each of the above mentioned cases are shown in Figs.6-8. Although these results are given only for the cases when the cage ascends, the results for the cases when the cage descends can be obtained just by exchanging the pressures of 1st and 15th floors.

In these figures, it can be seen that the pressure drop at the 1st floor due to the cage passing is the smallest when air supply is given to 1st and 15th floors and the shaft pressure is stable. In case of uniform air supply, the pressure change at the 1st floor is large, although the pressure difference between above and below the cage is kept constant.

5.CONCLUDING REMARKS

(1) In case of a pressurized elevator shaft with a moving cage, the computer model of smoke transport developed earlier by the author et al. can be used by a slight modification that $dV/dt \neq 0$ at a divided node in the elevator shaft.
(2) In this calculation method, the value of 0.6 which is modified from experimental data of Klote and Tamura to the flow coefficient for the space between the cage and the shaft wall gives an acceptable agreement with the experiment .
(3) The effects of different air supply patterns in a pressurized elevator shaft is investigated by using the computer model of smoke transport. Such flexibility of the computer model will be useful when we need close consideration on the availability of pressurized elevator shafts for the evacuation of the handicapped.

REFERENCE

[1] Klote;NBSIR82-2507,1982.5
[2] Klote,Tamura;ASHRAE Transactions,Vol.93,2217-2228,1987
[3] Klote,Tamura;Fire Safety Journal,Vol.11,227-233,1986
[4] Matsushita,Fukai,Terai;1st Fire Safety Science,1123-1132,1986

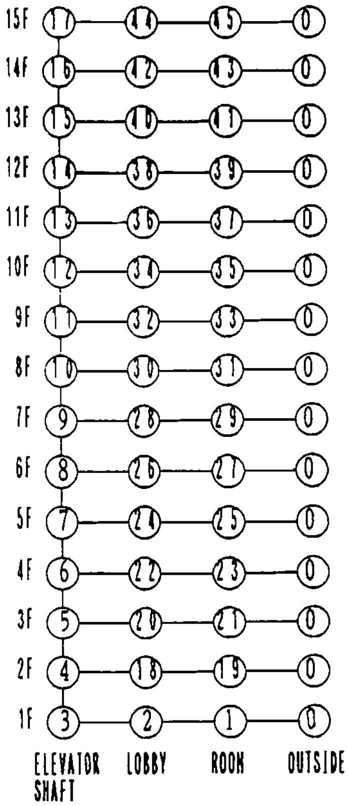

Figure-1. Graph of building for analysis

Table-1 Values used for analysis

	Values	Comments
Supply rate of air	8.05[kg/s]	Exp. condition by KLOTE
Cross-sectional shaft area	5.515 [m^2]	ditto
Area around elevator car	1.947 [m^2]	ditto
Area between shaft and lobby	0.131 [m^2]	Used value by KLOTE
Area between lobby and building	0.0901[m^2]	ditto
Area between building and outside	0.450 [m^2]	ditto
Flow coefficient for opening	0.65	ditto(estimated)
Flow coefficient for flow around elevator car	0.83 0.60	ditto modified value
Flow coefficient for shaft	5.0	Friction loss(estimated)

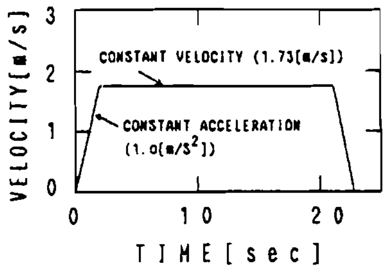

Figure-2. Time schedule of a moving cage in a elevator

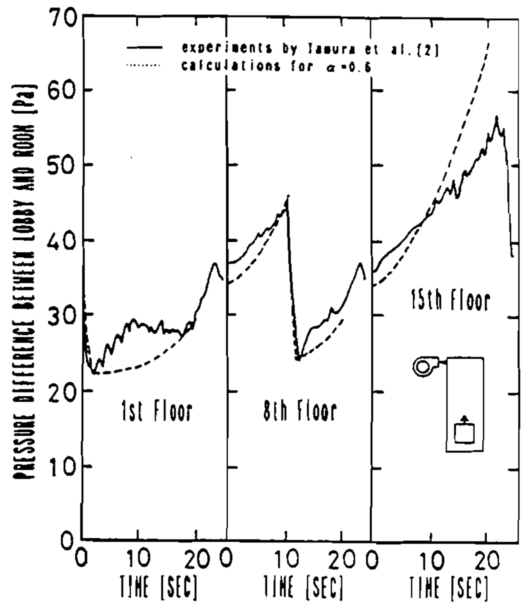

Figure-4. Comparison between the experiments by Klote and Tamura and the calculation by the computing method when a cage ascends in a pressurized elevator shaft

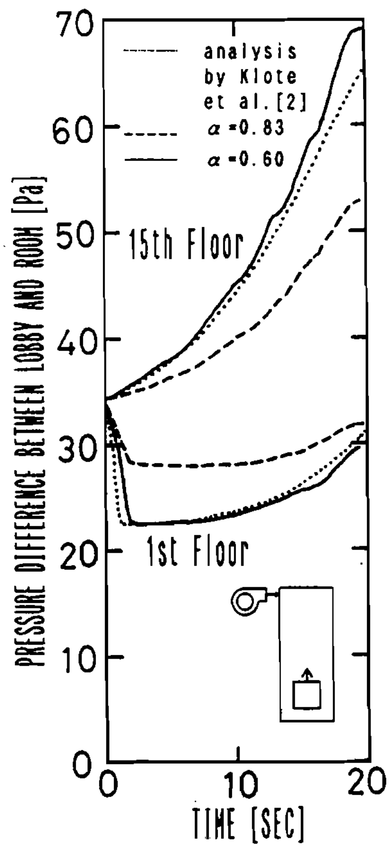

Figure-3. Comparison between the analytical results by Klote and Tamura and the calculation by the computing method when a cage ascends in a pressurized elevator shaft

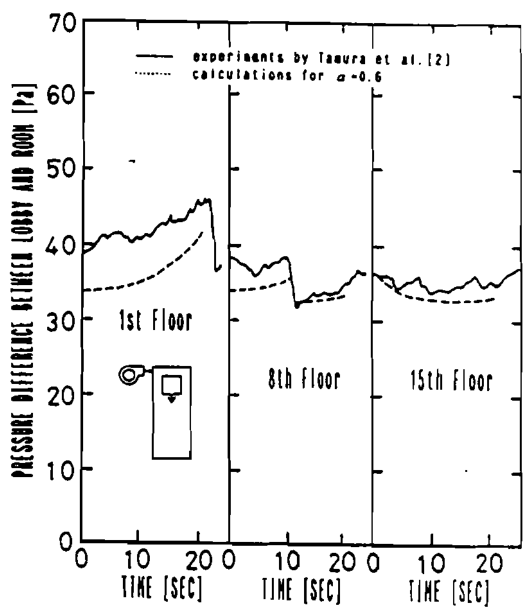

Figure-5. Comparison between the experiments by Klote and Tamura and the calculation by the computing method when a cage descends in a pressurized elevator shaft

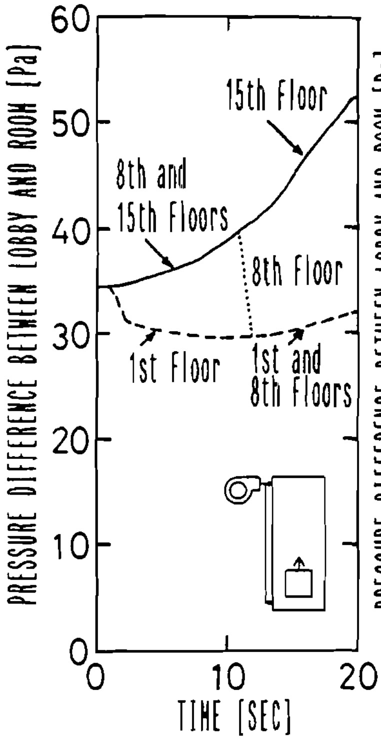

Figure-6. Calculation results when air supply on 1st and 15th floors and a cage ascends

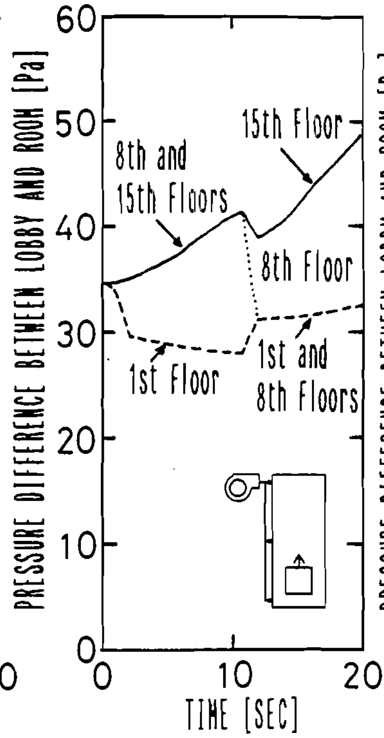

Figure-7. Calculation results when air supply on 1st,8th and 15th floors and a cage ascends

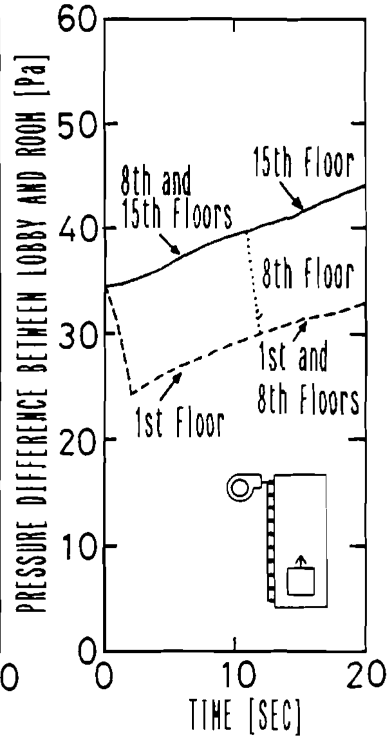

Figure-8. Calculation results when air supply on each of the floors and a cage ascends