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An Experimental Study of Maximum Allowable Pressure Differences for Staircases

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ABSTRACT

When a high-rise building is on fire, a forced draft system must maintain the fire protection staircase at a given pressure difference relative to other parts of the building to prevent smoke from coming in. The volume of forced draft is determined by both minimum smoke-resisting air pressure and the maximum allowable pressure difference for not obstructing the evacuation of people inside. The latter is connected with national conditions, which are obtained by employing a simulation method and statistics of a 200 person-time experiment measured in various high-rise buildings.

INSTRUCTIONS

As the vertical pressure distribution of a fireproof staircase is affected by the temperature difference between the inside and outside of a building, the opening position of an airblast hole, blast flow direction, flow resistance, and leakage along the route, a complicated pressure distribution will emerge in a vertical shaft. By taking a relatively unfavorable wind case as an example, the conditions of pressure distribution are shown in Figure 1.

Figure 1 shows that there are two pressure differences in the whole staircase—the maximum and minimum pressure difference points, the latter being the minimum critical value for keeping out smoke during a fire, and the former not to be greater than the maximum allowable pressure for guaranteeing the safe evacuation of personnel inside the building and allowing smooth passage past the fire gate into the evacuation staircase. The relationships between the maximum and minimum pressure difference as well as the flow resistance can be expressed in the following equation:

$$\Delta p_{max} = \Delta p_{min} + \Delta p_f + \Delta p_s$$
$$= \Delta p_{min} + (\lambda Y_{max}/de + \zeta) r v^2/2_g + C_c Y_{max} g p (1/T_o - 1/T_s)/R \quad (1)$$

where:

p_{max} = maximum pressure difference, Pa
p_{min} = minimum pressure difference, Pa
p_f = friction loss, Pa
p_s = smoke effect pressure, Pa

In a positive pressure forced draft system, the average pressure difference is obtained by a nonlinear combination based on maximum and minimum pressure differences.

$$P = 4/9 \left[\frac{p_{min}^{3/2} - (p_{max} + H' - \zeta \cdot \rho \cdot v^2/2g)^{3/2}}{p_{min} - p_{max} - H' + \zeta \cdot r v^2/2_g} \right] \quad (2)$$

where:

H' = total presure, Pa
$\zeta r v^2/2_g$ = movement loss, Pa

Therefore, to ensure smoke control of a staircase and safe passage of personnel, it is necessary to determine maximum and minimum pressure differences. These pressure differences are the precondition for correctly calculating positive pressure blast volume.

At present, the specification of different countries for maximum and minimum pressure differences in a staircase positive pressure blast are shown in Tables 1 and 2.

For the experimental study and theoretical analysis of minimum airflow speed, the conclusions of different countries are basically the same. As a theory for calculations, the values are correct.

From Table 2, it can be seen that the maximum pressure difference and average pressure difference are dif-

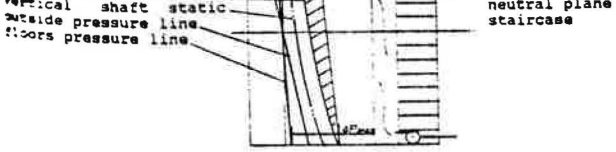

Figure 1 Vertical pressure distribution

TABLE 1
Minimum Speed of Smoke Prevention

Name of Country	Airflow Speed, m/s	Remarks
France	0.5	Open the doors
England	0.7	

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Table 2
Average Pressure Difference and Maximum Pressure Difference

Country and Standard	Pressure Difference, Pa
U.S. Unified Building Code	87.22
U.S. Basic Building Code	87.22
Canadian Building Code	99.96
Berlin Code	49
Australian Code	49
British Standard	60

ferent in different countries, mainly due to human factors (height, weight, etc.) and characteristics of the building ground. To this end, the human factors are essential for determining the maximum thrust for fire doors and the maximum pressure differences.

The survey conducted was based on high-rise buildings such as residences, hospitals, and offices. In the survey, consideration is given to age, sex, clothing, occupation, and the nature of the building floors.

In order to carry out experiments under the conditions present in ordinary buildings, the pressurizing system is simulated as a similar force of action concentrated on a point.

The acting force of a fire door under the condition of positive pressure is shown in Figure 2.

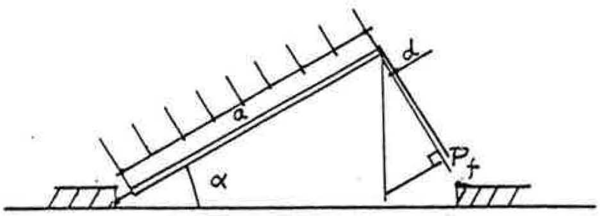

***Figure 2** Pressure action diagram*

The expression for thrust on a door is

$$\Phi(d\Delta p/d\alpha)\, A \cos\alpha = p_f \qquad (3)$$

where:

$\Phi(d\Delta p/d\alpha)$ = pressure difference in different places, Pa
A = area of door, m^2
p_f = force acting on the handle of a door, N

By similar method, the concentrated force for opening a door is obtained.

$$p_f = p_m + apA/(a - d)\cdot 2$$

$$\Delta p = 2[\Phi(d\Delta p/d\alpha\cdot\alpha)\cdot A\cdot\cos\alpha - p_m](a - b)/(a\cdot A)$$

where:

p_m = sum of resilient force and the frictional force of a doorframe, N
a = width of door, m
Δp = pressure difference, Pa
d = distance between the opening edge of a door and a door handle, m

Along with the changes of α, it is reasonable to use a concentrated force to replace the uniform action pressure difference. At the same time, when $\alpha = 0$, $p_f = p$, and $\Phi(d\Delta p/d\alpha\cdot\alpha)$, $\cos\alpha$ reaches a maximum value. Therefore, it is reasonable to consider the force of starting to open the door at the maximum thrust.

The conclusion of the experiment is shown in Figures 3, 4, 5, 6, and 7.

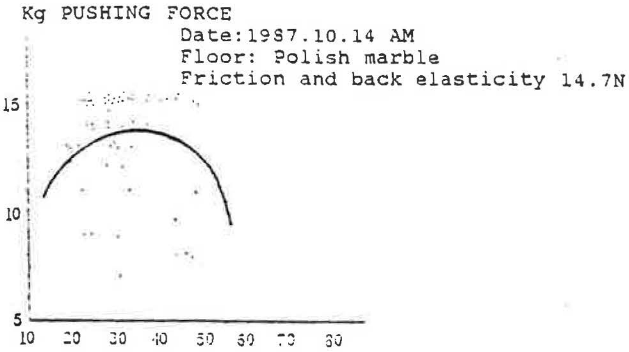

***Figure 3** Tianjin Architectural Design Institute*

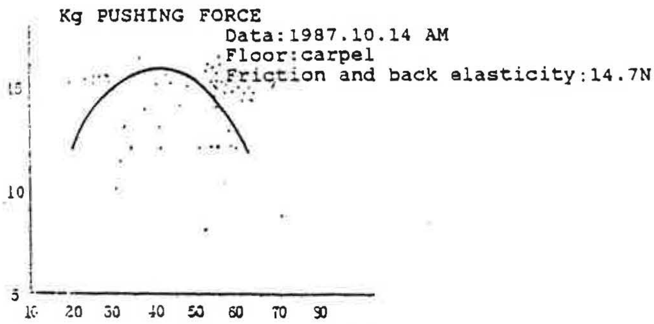

***Figure 4** Tianjin hotel*

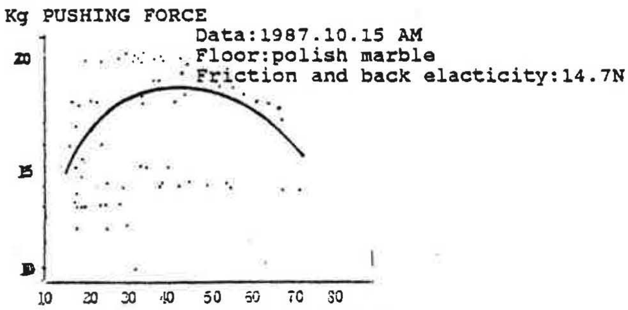

***Figure 5** First Centre Hospital*

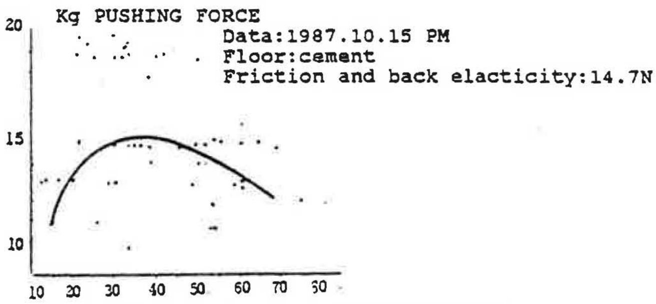

***Figure 6** San Duo Li high-rise residences*

The $\hat{\mu}$ and $\hat{\sigma}$ are obtained by a statistical methods. Table 3 shows the conclusion.

The results of the test were quite different.

Pushing force:

Office building = 147 N
Guesthouse = 151.9 N
High-rise residences = 142.1 N
Hospital = 137.2 N

TABLE 3
$\hat{\mu}$ and $\hat{\sigma}$ Character Conclusion

Experiment Place	Ages, $\hat{\mu}$	Ages, $\hat{\sigma}$	Pushing Force, $\hat{\mu}$	Pushing Force $\hat{\sigma}$	Δp_{max} Pa
T.A.D.I.	35.3	9.92	15.2	2.03	125
T.H.	48	14.4	16.2	1.65	164
S.D.L.	39.4	15.2	16.8	3.37	226
T.F.C.H.	34.5	13.5	16.6	3.63	189
Average	39.3	5.36	16.2	0.69	131

*T.A.D.I.—Tianjin Architectural Design Institute
T.H.—Tianjin Hotel
S.D.L.—San Duo Li High-Rise Residences
T.F.C.H.—Tianjin First Centre Hospital

Age of buildings:

Office building = 45 years
Guesthouse = 55 years
Hospital = 40 years
High-rise residences = 50 years

CONCLUSION

1. The experiment will have better representation and universality as the value of $\hat{\sigma}$ (age) gets larger.
2. If the value of $\hat{\sigma}$ (pushing force) gets larger, it means the pushing force is relatively concentrated in the building.
3. Maximum pushing force is related to the type of building and the fire door width (Table 4).

TABLE 4
Staircase Positive Presssure, Blast Pressure, and Pressure Difference

Type	Pressure, N	Pressure Difference, Pa — Fire Door Width 0.78 m	0.88 m	0.98 m	1.18 m
Office	149	117	105	96	81
Hotel	158	127	114	104	88
Residence	165	135	121	110	94
Hospital	163	133	119	109	92
Average	159	128	115	105	89

After calculating maximum or minimum pressure difference, the average pressure difference of flowing air can be obtained.

NOMENCLATURE

Δp = pressure difference
Δp_{max} = maximum allowable pressure difference between the stairwall, Pa
Δp_{min} = minimum allowable pressure difference between the stairwall, Pa
Δp_f = friction loss, Pa
Δp_s = smoke effect pressure, Pa
λ = coefficient of friction
Y_{max} = maximum difference from the air outlet to the opened door, m
de = equivalent diameter, m
de = 4 s/p
S = inside horizontal cross-sectional area of shaft, m
p = outer perimeter of shaft, m
ζ = coefficient of part friction
r = air density, kg/m
V = air velocity, m/s
g = gravitational constant, m/s
C_c = shaft cooling or heating factor
T_s = shaft air absolute temperature
T_o = outside air absolute temperature
p = atmospheiric pressure, Pa
R = gas constant of air
H = total pressure, Pa
$\Phi(d\Delta p/d\alpha \cdot \alpha)$ = pressure difference in different places, Pa
A = geometrical area of a door, m^2
P_f = force acting on the handle of a door, Pa
P_m = sum of resilient force and frictional force of a door frame, Pa
a = width of door, m
d = distance from doorknob to knobside of door, m
$\hat{\sigma}$ = variance
$\hat{\mu}$ = expectation

REFERENCES

Xu Ming. 1978. The study of smoke exhaust in highrise building. Tianjin.
Ministry of public security showing for the fire prevention standards for highrise of civil uses Beijing, 1983.
Klote, J.H., and Fothergill, J.W. Design of smoke control systems for building.
Tianjin University statistical teaching and research section statistics, 1980.
Yang Feng Xing and Lu Jun Liang. 1985. Number value analyses. Tianjin University.