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STUDY ON THE SMOKE MOVEMENT IN THE DOME WITH THE RETRACTABLE ROOF UNDER THE INFLUENCE OF OUTER WIND

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ABSTRACT

With the complication of buildings, in recent years, one of the characteristic in building's disaster prevention planning is that some engineering methods (zone model, field model, model experiment, etc.) have been used more and more often as estimating methods in preparing for a smoke retardation or a refuge planning.

Such a tendency can be always seen in large scale building projects and the estimating method often used is the zone model method.

In this paper, a dome model on the scale of 1/100 is used, and when it's on fire, the flow of smoke in the dome, especially under the influence of outer wind, is observed and surveyed. Finally, based on the experiment, the dangerous criterion are examined.

KEY WORDS: Smoke flow, model test, fire within large open-space buildings, retractable-roof domes

1. INTRODUCTION

At present, the bulk of smoke flow pattern analyses are carried out using two-layer zone models. Data from such analyses serves as an indispensable reference when designing optimum fire safety measures and evacuation procedures. The object of our particular research is the analysis of smoke flow patterns in domes with retractable roofs, which are entirely different from conventional structures. Smoke flow patterns in such structures are also thought to be affected by external wind forces, the extent depending on the degree to which the dome was opened. To overcome this problem, we decided to use a scale model for our research. Based on the results of this research, we then evaluated the effectiveness of various evacuation procedures in such structures.

2. EXPERIMENTAL METHOD

2.1. Outline of experiment

The test variables included the degree to which the roof was opened and wind velocity. Smoke concentration was then estimated. Based on the assumption that would be a direct related between temperature and smoke concentration, such concentration based on measurements of the dome's internal temperature. Table 2.1 indicates the parameter settings of the various tests.

Table 2.1 Experimental Case

	NO-1		NO-2		NO-3		NO-4		NO-5	
	Real	Model	Real	Model	Real	Model	Real	Model	Real	Model
External wind (m/s)	—	—	2.5	0.25	5.0	0.5	7.5	0.75	10.0	1.0
Heat value (kW)	25,000	0.25	25,000	0.25	25,000	0.25	25,000	0.25	25,000	0.25
Wind direction	0°	0°	0°	0°	0°	0°	0°	0°	0°	0°
	45°	45°	45°	45°	45°	45°	45°	45°	45°	45°
Retractable roof	Close	Close	Open	Open	Open	Open	Open	Open	Open	Open

2.2. Scaling law between model and actual building

(1) Scaling law between non-isothermal flow fields. The fire source in the dome in question is assumed to be small. The non-compression hypothesis may be applied to the temperatures of all areas apart from the areas close around the fire itself. Because the smoke concentration is governed by the natural internal air flow within the dome and don't affect flow field, the model will be able to perform realistic smoke flow simulations as long as the parameters of a non-isothermal fluid movement are satisfied. If the turbulence is sufficiently developed, π -number which needs to be satisfied is as follows:

$$Ar = g\beta\Delta\theta L / U^2$$

where

g = gravity
β = volume expansion coefficient
$\Delta\theta$ = temperature difference
L = represented length
U = represented velocity

(2) Heat source boundary conditions. Since the aim of the experiment is the prediction of the flow patterns of heated air and gas, side effects such as heat from the walls affecting the overall air flow may be ignored. Thus, unison of nondimensional values for radiation was also ignored and only the convection heat transmission value similarities were considered as follows:

$$Q^* = C_P\rho L^2 U\Delta\theta / Q$$

where

Q = heat value
C_P = specific heat
ρ = density

2.3. Test apparatus

(1) Model. We decided to construct the model on a scale of 1/100. Figure 2.1 shows a cross section of the model.

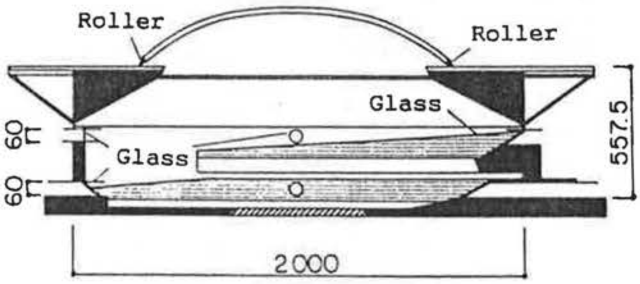

Figure 2.1 Cross Section of Model

(2) Heat source. For our tests, we used the standard fire source No. 2 which was modeled from the fire source of experimental fire. Due to the difficulty in changing the heat value during the experiment, we employed a fire source with a simplified heat value as indicated in Figure 2.3. The fire source was positioned in the middle of the field.

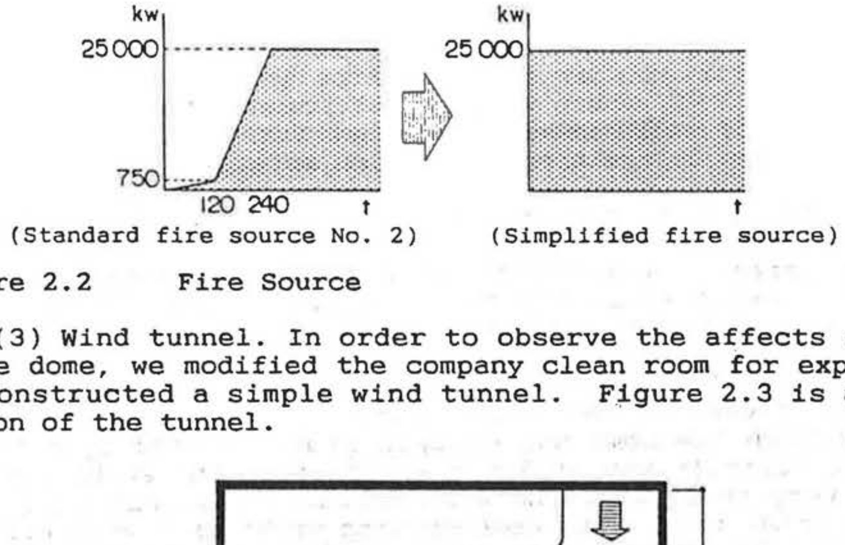

Figure 2.2 Fire Source

(3) Wind tunnel. In order to observe the affects of wind on the dome, we modified the company clean room for experiment and constructed a simple wind tunnel. Figure 2.3 is a cross section of the tunnel.

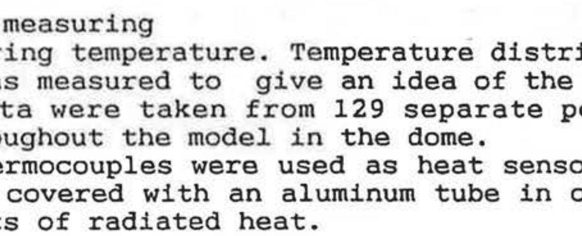

Figure 2.3 Simplified Wind Tunnel

2.4. Method of measuring

(1) Measuring temperature. Temperature distribution within the building was measured to give an idea of the flow patterns of hot air. Data were taken from 129 separate points located vertically throughout the model in the dome.

T-type thermocouples were used as heat sensors. The thermocouples were covered with an aluminum tube in order to minimize the affects of radiated heat.

(2) Wind speed measuring. Smoke flow patterns in the building were estimated by combining the results of the internal wind velocity measurements with the results of the flow visualization. Wind velocity was measured using a multipoint wind velocity meter which measures wind velocities at 24 separate points simultaneously.

(3) Flow visualization. Titanium tetrachloride and fluidized paraffin was used as a tracer in the flow visualization. The various stages of the visual experiment were recorded on a micro-video camera, a fiber scope camera and a normal camera.

3. RESULTS AND DISCUSSION

3.1. Predicting smoke concentration and evaluation standards

In our tests we employed the smoke concentration prediction method as described in Reference 3).

$$\int_0^{t_e} \Delta T^2 dt \leqq 4.0 \times 10^3$$

where

ΔT = temperature difference

t_e = evacuation time

From the above equation we can see that when ΔT is constantly at 2 °C, evacuation time t_e comes to 16.67 minutes more than a time for safe evacuation. From this we can say that as long as ΔT = 2 °C, there will be sufficient time to escape from the effects of smoke safely, and that this should be used as a yardstick when determining evacuation safety.

3.2. Smoke diffusion with the roof open (Parameter settings No. 2-5)

In order to ascertain the affects of external wind on smoke diffusion while the roof was open, wind was applied to the dome to simulate wind velocities of 2.5 m/s, 5.0 m/s, 7.5 m/s and 10.0 m/s.

As could be expected, smoke diffusion increased with wind velocity intensity. The results indicate that nearly all of the smoke within the dome had escaped from the roof opening when the wind velocity was at 2.5 m/s, and that the smoke diffusion became very small when the wind velocity had increased to 5.0 m/s. In other words, the dome opening works as a very effective smoke vent as long as the wind velocity is between 0-5.0 m/s. Although subject to a simulated wind velocity of 7.5 m/s there appeared to be a slight amount of smoke around the arena area, it was determined that the concentration of this smoke was insufficient to cause any harm. At 10.0 m/s, smoke diffusion within the building occurred at an advanced rate. As the behavior of the smoke changed so rapidly there is thought to be a critical point between 7.5-10.0 m/s. Nevertheless, the regions in which persons were likely to be were determined to be safe as no high concentrations of smoke were detected. Similar results were observed in the flow visualization.

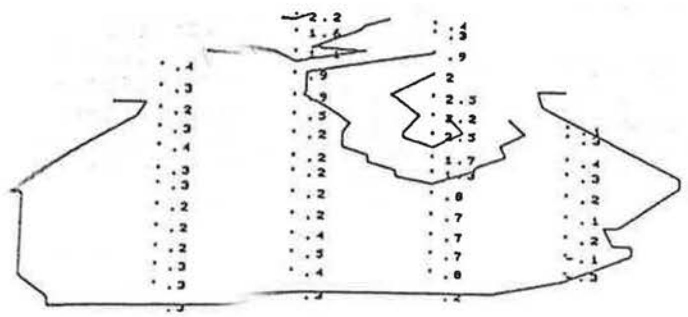

Figure 3.1 Temperature Distribution (Real Version Velocity = 2.5 m/s)

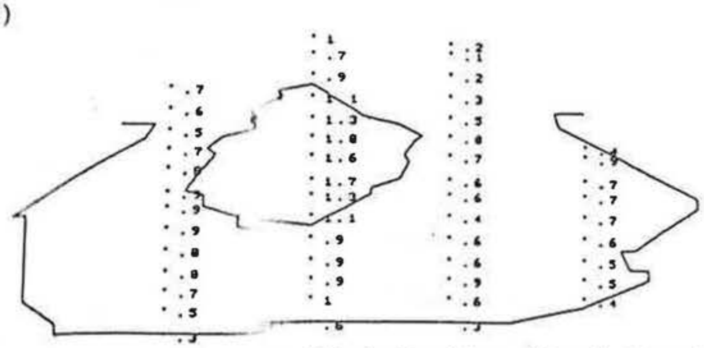

Figure 3.2 Temperature Distribution (Real Version Velocity = 5.0 m/s)

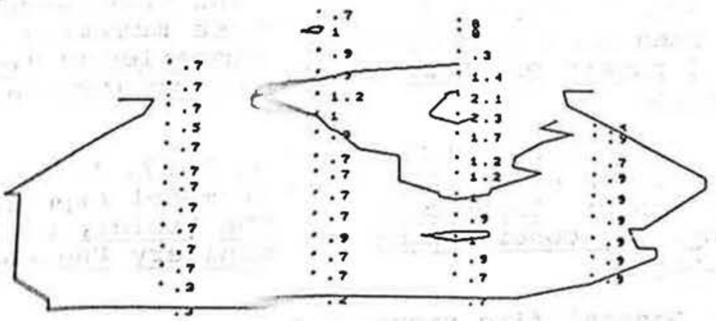

Figure 3.3 Temperature Distribution (Real Version Velocity = 7.5 m/s)

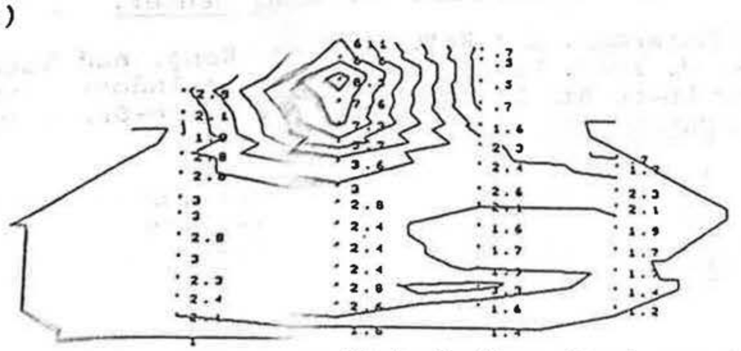

Figure 3.4 Temperature Distribution (Real Version Velocity = 10.0 m/s)

4. CONCLUSION

Our investigation began with research into recent developments in fire prevention technology. We then carried out an investigation into smoke flow pattern prediction technology, which we considered to be of vital importance in minimizing fire casualties. We then conducted a series of tests on a model of a retractable dome to simulate smoke flow within such buildings. The following are our conclusions:

1. In the smoke diffusion test with the roof in a fully opened position, the smoke level was determined to reach a level equivalent to $\Delta T = 2°C$. This was concluded after making a comparison with the two-level zone model results. However, as it was also concluded that this could vary depending on the test conditions, further investigation into the relationship between the two results will be needed.

2. Results of the ordinary smoke flow tests and the tests which took into account external wind factors were markedly different.

3. Most of the smoke escaped through the roof opening when the external wind velocity was between 0-5.0 m/s. This occurred even when the roof was fully opened. This indicates the opening acted as an effective smoke vent.

4. When the roof was fully opened and the external wind velocity reached 10.0m/s, the smoke was dispersed within the dome, however, the concentration of smoke still did not reach dangerous levels in the areas where people were likely to be.

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