SMOKE MANAGEMENT AND EGRESS ANALYSIS OF THE CKS AIRPORT EXTENSION II PROJECT

K.H. Yang and S.K. Lee
Mechanical Engineering Department, National Sun Yat-Sen University, Kaohsiung, Taiwan 80424, R.O.C.

ABSTRACT

In this study, smoke management and egress analysis of a new airport was simulated, followed by full-scale experiments. The experimental work validated the analysis successfully which warranted the effectiveness of the emergency procedure of this airport.

1. INTRODUCTION

Due to the economic booms in Taiwan, The CKS airport proceeds for its extension II project and is scheduled for commercial operation in February 2000. This airport consists of four floors with the atrium ceiling height of 22.5m as shown in Fig. 1.

The prescriptive fire protection code in Taiwan provides some guidelines for smoke management system designs. In item 189, strict enforcement of smoke extraction rate per m² floor area, namely 1 m³/min², should be followed, together with 50cm and 80cm depth smoke barriers should be installed on either above or below grade floors for compartmentation.

For offices and duty-free shop areas, this prescriptive code maybe appropriate in providing basic requirement for smoke removal, although the mechanical smoke exhaust rate is doubtful. But for large spaces with atrium, such as the 4F departure hall, the dilemma encountered is that any design guide for smoke management system is simply non-existant. In this study, a performance-based design of the smoke management system of the 4F departure hall was proceeded, followed by a full-scale experiment for validation. Quantitative risk assessment using the Monte Carlo method has been performed to evaluate the effectiveness of emergency procedure in integrating smoke management and egress analysis.

2. THE SMOKE MANAGEMENT SYSTEM ANALYSIS

The departure hall is a large-span atrium with 200m x 110m x 22.5m in size. The design concept is to utilize the large space for smoke reservoir, followed by mechanical smoke extraction on top, so that a smoke-free escape route can be maintained for egress.

Computer simulation using CFAST [1] was first conducted, to analyze the natural fill process of an ultra-fast t² fire, sized 5MW, 10MW and 20MW respectively.

The simulation result in Fig. 2 indicated that in 12 minutes, 16.1m, 15.3 m and 14.5m clear height can be maintained in a 5 MW, 10 MW or 20 MW fire.
3. FULL-SCALE HOT SMOKE TEST

To validate the CFAST natural filling simulation result, a full-scale hot smoke test experiment was conducted in December, 1998. A gasoline pan with 2.1m in diameter (Heat Release Rate is 7.5MW approximately) was set on fire and the smoke natural filling process was recorded by a video camera and redundantly checked by thermocouples. The experimental result was shown in Fig. 3, which was then plotted in Fig. 2 as a dotted line. The experimental result correlated very well with that of simulations. The deviation is partly due to that CFAST is based on two-layer zone model, and the transition layer between the hot and cold can not be counted clearly. While on the other hand, it cannot be identified easily by bare eyes.

Fig. 2: The Departure Hall atrium smoke natural-filling simulation and experimental result

Fig. 3: The full-scale experiment result of hot smoke test in CKS II Airport Departure Hall, 1997
4. RENOVATED MECHANICAL SMOKE EXHAUST SYSTEM

Although the huge atrium can be utilized as smoke reservoir effectively, emergency ventilation is considered a necessary redundancy in case of flashover, or sprinkler failure, and to facilitate more efficient fire-fighting as well. The authors proposed to integrate mechanical smoke exhaust by upgrading the existing eleven atrium ceiling fans into fire-grades. These fans were originally designed for ventilation purpose only. These eleven ceiling fans were with 500 m$^3$min$^{-1}$ capacity each installed to operate on an intelligent mode controlled by thermostats as shown in Table 1. After they were fire-graded to be adapted for smoke removable as well, the emergency operation mode was added. This is considered an efficient and cost-effective solution.

The renovated mechanical smoke exhaust system performance was simulated as shown in Fig. 4, where clear height over 14m can be maintained for over 1800 seconds, or 30 minutes and considered a satisfactory design.

Table 1: The top ceiling fans operating modes in CKS II Airport

<table>
<thead>
<tr>
<th>OPERATING MODE NO</th>
<th>DESCRIPTION</th>
<th>OPERATING CONDITION</th>
<th>EXHAUST AIR FAN (EAF-□□□□□□□□□□)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shut Down</td>
<td>Normal</td>
<td>R01 R02 R03 R04 R05 R06</td>
</tr>
<tr>
<td>2</td>
<td>30$&lt;t&lt;34$</td>
<td>Normal</td>
<td>x x x x x x x</td>
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<tr>
<td>3</td>
<td>34$&lt;t&lt;37$</td>
<td>Normal</td>
<td>x x x x x • x</td>
</tr>
<tr>
<td>4</td>
<td>37$&lt;t&lt;40$</td>
<td>Normal</td>
<td>• x x • • x</td>
</tr>
<tr>
<td>5</td>
<td>Fire</td>
<td>Emergency</td>
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OPERATING MODE NO | DESCRIPTION | OPERATING CONDITION | EXHAUST AIR FAN (EAF-□□□□□□□□□□) |
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<tbody>
<tr>
<td>1</td>
<td>Shut Down</td>
<td>Normal</td>
<td>R07 R08 R09 R10 R11</td>
</tr>
<tr>
<td>2</td>
<td>30$&lt;t&lt;34$</td>
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<td>3</td>
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<td>5</td>
<td>Fire</td>
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• ON  x OFF

Fig. 4: The improved mechanical smoke exhaust system simulation result
5. EGRESS ANALYSIS

The prescriptive code in Taiwan only limited the farthest walking distance from exist in not exceeding 30m and considering a fixed 1ms\(^{-1}\) foot traffic for evacuees. This over-simplified rule-of-thumb was almost always employed by local architects to check their egress design. In panic, the crowd trapped in a fire site could never run in such a steady state – steady flow pattern, unless in very rare cases where free walking is possible [2]. In 1997, Yang et al. performed a full-scale egress experiment in Taipei Mass Rapid Transit System [3], where it was found that the crowd movement velocity is dependent on its density as shown in Fig. 5. The egress calculation of CKS II atrium was performed by adapting this data and using the calculation formula developed by Japanese Building Research Institute [4], where it was stated:

\[ T_{\text{max}} = \max(t_1, t_2) \]

where

\[ T_{\text{max}} = \text{egress time (s)} \]
\[ t_1 = \text{walking time needed to the farthest exit (s)} \]
\[ t_2 = \text{time needed to pass through exits (s)} \]

\[ t_2 = \frac{Q}{n \times b} \]

where

\[ Q = \text{effective evacuee number (-)} \]
\[ n = \text{evacuation flow rate (P/ms)} \]
\[ b = \text{effective exit width (m)} \]

The calculation result is a total time of 139 seconds. Furthermore, the SIMULEX [5] was used, results in a similar result as shown in Fig. 6.

The deviation is derived from the basic algorithmic difference between the two. The BRI model is based on the correlation between crowd density and the egress velocity, which has been adapted from various full-scale egress experiments. On the other hand, the SIMULEX decides its egress velocity by judging the distance between two evacuees, so that the dynamic response such as crowd movement bottlenecks, etc. can all be visualized. The SIMULEX result is considered more vivid in simulating the actual evacuation process, and resulting in 31 seconds more in egress time in our case.

![Experimental Data vs. SFPE formula](image)

**Fig. 5: The relation between flow velocity (V) and density (D) of the crowd**
6. QUANTITATIVE RISK ANALYSIS

The complete emergency procedure includes the following time steps:

1. fire and/or smoke detection
2. identification of fire location
3. control center notification
4. alarm and announcement
5. egress route selection
6. egress in process
7. egress completed

Each step takes some time to complete and the time needed is dependent on the technical specification in each subsystems designed. The smoke management system should maintain at least this complete time period to provide a smoke-free escape route. However, the fire and smoke detectors, the annunciation, and the humane reaction in the control center or the evacuees may respond differently, depending on the occurring fire sizes, fire location and unknown reasons. For example, the beam-type smoke detection system may be specified to activate in 60 seconds after fire occurs, but it could actually take 30 seconds and react properly if fire occurred right underneath, or vice versa. The humane factor also plays a similar role to identify a fire and call the control center, or to direct the evacuee for egress.

To consider this uncertainties and probabilities in each time step, the Monte Carlo method [6] was adapted in this study. Each time step was assigned a normal distribution curve with the maximum occurrence probability specified according to its equipment specifications. Therefore, in simulation process, the beam detectors not only responded in 60 seconds as they are specified by the designers, but could also react in 50, 40 and 30 seconds, etc. only to much less occurring probabilities.

The quantitative risk assessment was performed for CKS II departure hall. The simulation result shown as Fig. 7 indicated that the “most probable” time needed for the complete emergency procedure is 408 seconds, with 366 seconds and 450 seconds as lower and higher margins.

In comparison, the renovated smoke exhaust system keeps a clear height of 7.4m for longer than 740 seconds and after, which warranted the successful performance of the smoke management, egress plan, and the whole emergency procedure.
7. CONCLUSIONS

The main goal of a smoke exhaust system is not for smoke removable, but to provide a smoke-free escape route within certain time period. The egress plan should be designed to complete the whole emergency procedure within that time allowed, with various probabilities encountered. The research performed in this study validated the CKS II airport emergency systems can do just that, which is now ready for commercial operation.

ACKNOWLEDGEMENT

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REFERENCES