行政院國家科學委員會專題研究計劃成果報告

捷運地下車站人流分佈與通風策略研究（I）

計劃編號:NSC 90-2212-E-002-240

執行時間:90/08/01 ~ 91/07/31

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ABSTRACT

We investigate the effectiveness of the smoke control schemes of Gong-Guan Subway Station, a typical subway station of Taipei Rapid Transit System and whose mechanical control systems are also a kind of standard equipment in modern subway station. The three-dimensional smoke flow fields under various kinds of fires are computed by the computational-fluid-dynamic technique and results are illustrated on various cross sectional planes. Results indicate that, the stack effect plays a deterministic role on smoke control when fire occurs near the stairwells; under such a circumstance, no mechanical smoke control is necessary. When fire occurs in other places, such as on the edge or the center of platform, the current mechanical control schemes of GGSS are effective; namely, the smoke can be well controlled, either is confined to a small region or is evacuated out of the station, leaving the four exits free of smoke so that the passengers can escape through it.

Keywords: fire, smoke control, subway station

1. INTRODUCTION

Fires in subway stations happened frequently in history, especially in the past two decades when subway has been becoming a major transportation scheme in metropolitan area. Two well-known major accidents have made indelible imprints in our memories, both causing a large number of victims [1]: One happened in London King's Cross subway station and one in Baku (capital of Republic of Azerbaijian) subway tunnel. The fire in King's Cross station happened in November 18, 1987, causing 87 people either die or serious injure. The fire in Baku happened in October 29, 1995, which had been even more serious, the hot air and toxic smoke killed 337 people and left 227 seriously injured. From the results obtained from the computational fluid dynamics (CFD) simulation of King's Cross fire [2], it was found that the smoke movement in this complicate-structured station is hardly predicted and the smoke control is crucial in fire emergency. In the present paper we study the effectiveness of the smoke control systems of GGSS: the tunnel ventilation fan (TVF), the under platform exhaust (UPE) system, and the smoke evacuate gate (SEG). We employ computational-fluid-dynamic (CFD) approach to investigate the three-dimensional smoke flow field in GGSS. Special emphasis is placed on the evolution of the smoke propagation under smoke control. We note also that, in fires occurring in an enclosure such as the subway station, a natural convection phenomenon named "stack effect" may play a significant role in smoke propagation when no mechanical system is engaged. It is because in most enclosures there are various kinds of structural vertical spaces through which the buoyancy force of hot smoke is enhanced. The pressure difference induced by stack effect can be much larger than that due to other driving forces, such as expansion of combustion gas, wind effect, and so on [3]. As soon as the stack effect forms, the smoke generated in enclosure will move towards and into the vertical shafts, such as the stairwell, the shaft of elevator, and the vertical shaft of ventilation system, becoming an important phenomenon to which the design of smoke control system has to seriously consider. Accordingly, the stack effect is also one of the major issues to be studied here.

2. ARCHITECTURE OF GGSS

As a typical midway station of TRTS (Fig. 1), the GGSS has two floors: the platform floor at bottom, in which an island-platform sits between rails of opposite bound, and the lobby floor at top, in which two hallways at the two ends of the floor connect the lobby and four stairwells (or exits. The length of the station is142.1m and the

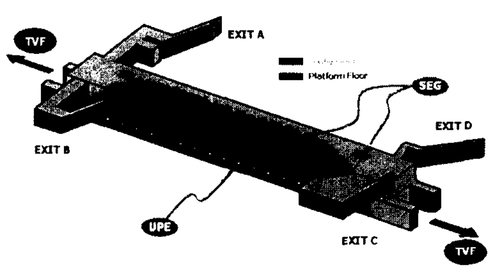

Figure 1. A schematic drawing of the Gung Guan Subway Station (GGSS).

width is 17.9m. The height of the lobby floor is 4.15m and that of the platform floor is 5.15m. In view of the beauty of the interior of station and the relaxation of the mental-pressure due to the space limitation of platform floor, a large area at the center of lobby floor is cut, remaining two two-meter-width passages on the edge and two hallways connecting the stairwells. This cut of the central portion of lobby floor, unfortunately, enhances the buoyancy force of hot smoke, making the smoke control in GGSS more difficult.

To ensure the smoke be well controlled during fires, the station is equipped with three mechanical systems serving to evacuate smoke (Fig. 1): (1) The TVF, locating in the tunnels near the two ends of the platform floor, sucking the air into tunnels and evacuating to the road surface, inducing approximately a 5m/s wind into tunnels. (2) The UPE, locating below the platform, having totally 36 openings along the two sides of the platform (18 on each side), inducing approximately a 2m/s flow into the opening. (3) The SEG, locating on the ceiling of lobby floor, having totally 8 gates uniformly distributed along the ceiling, inducing approximately a 2m/s flow into the gate. As fire occurs, the person-in-charge of control center will observe both the location and the development of fires and then decides which system shall turn on to evacuate smoke.

There is an additional setup in GGSS regarding the smoke control and is also a necessity to accommodate to fire-safety regulation in Taiwan. Namely, there are seven smoke-blocking walls (SBW) hanging down from the ceiling and each SBW is approximately 1.3 meter high. These walls are designed to confine the smoke attached to the ceiling. In GGSS, the ceiling is divided into eight zones. This scheme is named as the smoke-zone compartment, with which the smoke propagation in large open space will be damped significantly and the life-threaten to passengers due to smoke can be relaxed.

3. SMOKE PROPAGATION IN GGSS

To illustrate the smoke propagation in GGSS, we begin with the flow in GGSS induced by a fire of 5MW occurring on the left hallway of lobby floor, as shown in Fig. 2, in which no mechanical smoke control system is active.

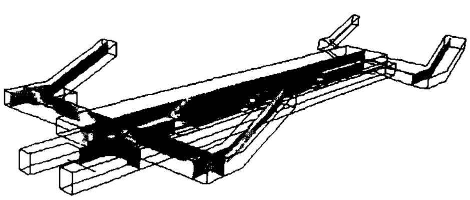

Figure 2. Three-dimensional stereo-views of smoke distribution in GGSS due to a fire locating on the left of lobby floor.

In this three-dimensional picture, there are five vertical cross sectional (VCS) planes. In each plane the temperature distribution represented by colors is shown, orange accounts for hot air about 500 ^{o} K or higher, and blue for cool air of room temperature. The case shown is at t = 4min, part of the smoke has moved into the center of lobby floor as well as down to the platform floor, while most of the smoke moves into the two stairwells to evacuate out of the station. It is interesting to note that part of the flow moves to the left, which is due to the stack effect occurring in the two stairwells on the left. In other words, the hot smoke reaches to the two stairwells at left first, which in turn induces a strong buoyancy flow in the stairwells, making the stairwells become low pressure zones and suck the air out of the station. Similar phenomena are also found in other cases under different fire conditions.

Figure 3 illustrates a series of pictures regarding the temperature distributions on the middle VCS plane under fires at different location. The results are categorized into three groups.

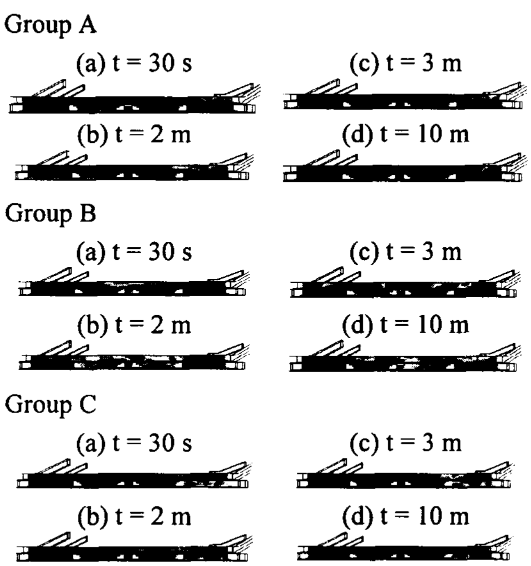

Figure 3. Smoke propagation due to fires at different locations.

In Group A, the fire occurs on the right of lobby floor, a small portion of smoke propagates to the left at t = 2min, while eventually moves back to the right and evacuates out of the station through the two stairwells due to the stack effect. In Group B, the smoke propagates rapidly and moves into every corner of station in a short time, rendering a serious situation threatening the safety of passengers. In Group C, the fire locates on the right of platform floor, the smoke moves into the center of station within a few minutes. Although the smoke eventually moves back to the right of station to evacuate out of the station because of again the stack effect, the smoke has stayed in a large part of station for more than 10min. This has led to a situation that one may not evacuate all the passengers in station within the 6min critical-limit suggested by NFPA [9], which is followed by most subway-system regulations including TRTS.

5. EFFECT OF SMOKE CONTROL

In GGSS there are three mechanical systems serve to evacuate smoke (see Fig. 1): TVF, UPE and SEG. In this section, we examine the performance of these smoke-control systems. The case examined is the fire locating at the center of platform floor because it is the most difficult case as far as smoke control is concerned. The results are again categorized into three groups. In Group A no smoke control is engaged (Fig. 5A), the smoke generated from the fire at the center of platform propagates rapidly in the station, rendering a dangerous environment to passengers. With active SEG (Fig. 5B), the smoke distribution is slightly improved, most of the smoke is confined to the central region of station while is still to some extent threatening the passengers because the smoke are quite close to the four exits. This is because the smoke generation rate of fire is larger than the evacuation rate through SEG. With active TVF and UPE (Fig. 5C), the smoke is well confined to a small region in the center of station, leaving the four stairwells free of smoke. This is because most of the smoke are evacuated through TVF and UPE.

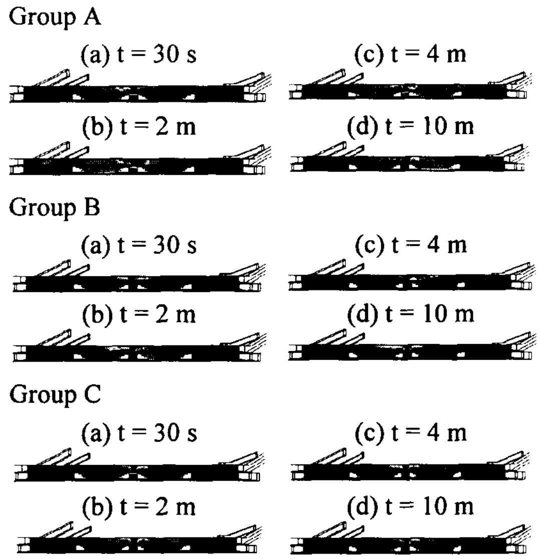

Figure 5. Effects of smoke control due to different smoke control system.

To illustrate more clearly the power of TVF and UPE, we show the detail flow structure of Fig. 5C(d) where the smoke is well controlled under the action of TVF and UPE. Figure 6(a) shows the velocity vectors in a HCS plane four meters above the platform floor. It is seen that strong winds (orange vectors) are induced near the two stairs and the four tunnels, which is obviously due to the strong suction from TVF and UPE inducing the fresh air to come down from the lobby floor through the cut-off of the lobby floor. Figure 6(b) shows the velocity vectors in a HCS plane one meter below ceiling, confirming that the fresh air is sucked into the station through the four stairwells. Note that the induced flow in Exit C is smaller than the others because of its larger cross sectional area. Figure 6(c) show the VCS plane cutting the two exits at the right-hand-side of the station, indicating again the strong winds induced by the suction of

TVF and UPE pass through the stairwells rapidly.

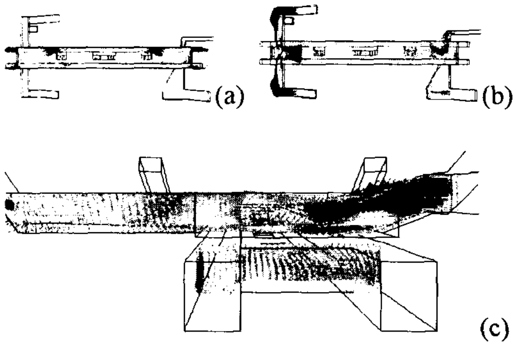

Figure 6. Velocity vectors in different cross sectional planes at t = 6m.

6. CONCLUSIONS

We have employed computational fluid dynamics technique to investigate the propagation of the smoke generated by various kinds of fire occurring in the GGSS of TRTS. We first investigate the effectiveness of the smoke control systems of GGSS when fires occur in different possible locations. Results suggest that: (1) As fire occurs at the two ends of lobby floor, the stack effect will predominate the smoke propagation and the smoke will evacuate through the stairwell(s) near the fire; no mechanical smoke control is needed. (2) As fire occurs in the central area of platform floor, the buoyant flow will move upwards, impinges on the ceiling and spreads rapidly to every corner of station. Under such a circumstance, all the three mechanical smoke control systems shall turn on, then most of the smoke will be sucked out of station through the TVF in tunnels and the UPE under platform, and a small part of smoke will evacuate through SEG, leaving the four exits through which the passengers are supposed to pass to evacuate out of station free of smoke. (3) As fires occurs in the two ends of platform, the smoke will also move rapidly to both lobby and platform floors if no mechanical smoke control is engaged, but will be evacuated out of station efficiently when the TVF close to the fire is active. In conclusion, with present mechanical smoke control systems of GGSS, the smoke generated by a fire of 5MW can be well controlled, leaving emergency-passages free of smoke so that the passengers can evacuate out of station smoothly. Note that 5MW is supposed to be the largest-possible fire will ever occur in the subway station. While a fire larger heat release rate, say 10MW, can also be possible when the train got fire [7].

Acknowledgements

The financial supports for this research from both SinoTech Engineering Consultant Inc. and National Science Council under grant NSC 89-2212-E-002-61 are gratefully appreciated.

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