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A CFD Analysis of Station Fire Conditions in the Buenos Aires Subway System

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ABSTRACT

This paper presents results of a study where computational fluid dynamics (CFD) was the numerical tool used to analyze the ventilation performance in stations of the Buenos Aires Metro subway system. Both natural and mechanical ventilation options were studied. The study showed that although natural ventilation was sufficient to maintain the temperature criteria, it presented a potential egress problem by letting hot gases leave through the entranceways. Mechanical ventilation, through the use ofjetfans, solved this problem, purging the hot gases away from the fire and toward the tunnels.

INTRODUCTION

Most of the Buenos Aires subway system was designed and constructed between 1910 and 1950. Today, the system consists of 37 kilometers of tunnels connecting 63 stations along five lines. As with most subway systems constructed before the mid-1980s, little or no consideration was given to fire-life safety. This was probably due to insufficient information concerning passenger evacuation from tunnels and the ventilation required to control the direction of smoke movement to provide a safe egress path.

Emergency operations generally result from a malfunction of the transit vehicle. The most serious emergency is a stopped train on fire in a tunnel or a station, disrupting traffic and requiring passenger evacuation. A computational fluid dynamics (CFD) analysis was performed to show that the recommended ventilation alternative will be adequate to control the spread of smoke and to provide a progressively better and safer evacuation path in the station.

This paper presents the results and conclusions of the CFD analysis, which is an integral part of a ventilation study for Buenos Aires Metro (Parsons et al. 1997). The objectives of that ventilation study included the following:

- Identify and evaluate feasible and cost-effective ventilation alternatives to meet the current industry standard, the National Fire Protection Association's *NFPA Standard 130, Standard for Fixed Guideway Transit Systems* (NFPA 1995).
- Perform subway environment simulation (SES) to determine the ventilation requirements for a tunnel emergency for a selected section of the system (U.S. DOT 1980).
- Perform CFD simulations to identify the most effective ventilation operating mode during a fire emergency in a station using a general purpose three-dimensional CFD program.
- Develop a conceptual construction cost estimate for the systemwide implementation of the ventilation improvements considering the physical and operational limitations associated with an existing system.

PERFORMANCE CRITERIA

NFPA 130, 1995 Edition

NFPA Standard 130 (NFPA 1995) addresses fire protection and life safety requirements in underground, surface, and elevated fixed guideway transit systems. NFPA 130 is the only published transit fire-life safety standard in the world. The 1995 edition has been approved by the American National Standards Institute. It represents the state-of-the-art require-

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ments for fixed guideway transit systems. NFPA 130 requires emergency ventilation in stations and tunnels to protect the passengers and employees from a fire or smoke generation. The criteria specified in the standard are as follows:

- The emergency ventilation system shall produce airflow rates to provide a stream of noncontaminated air to passengers and employees in a path of egress away from a train fire and to prevent back-layering of smoke in a path of egress away from a train fire.
- The maximum temperature in the path of evacuation shall not exceed 60°C, ignoring radiant heating effects.
- The air velocity in the path of evacuation shall not exceed 11 m/s; air velocities above this level may cause difficulty in walking.

To preclude imposing requirements on older existing transit systems, which may be impractical and/or cost prohibitive, NFPA 130 does not mandate that existing systems comply with these ventilation requirements. Almost all of the Buenos Aires Metro was built long before NFPA 130 was issued. The system has for many decades provided safe and reliable service. Major fires that would require ventilation systems to assist passenger safety have been rare over the history of the transit system. However, Buenos Aires Metro plans to improve the subway ventilation based on NFPA 130 with priority given to meeting the requirements for low-intensity fires throughout the subway system. For new subway systems, recommendations are for the high-intensity fire of a train fully engulfed in fire.

Fire Heat Release Rate

The train fire heat release rate used for the analysis was a low-intensity fire of 1.8 MW (NYC 1994). This value corresponds to a train fire that involves only the undercar combustible contents.

VENTILATION ALTERNATIVES

The analysis of alternative ventilation strategies focused initially on identifying and evaluating the potential use of various strategies that have been used successfully in the industry. These strategies include (1) end-of-station fan plants, (2) mid-tunnel fan plants, (3) propeller fans, (4) jet fans, and (5) station mechanical ventilation. In evaluating these strategies, careful consideration was given to space constraints for locating equipment within and around the stations, cost-effectiveness, and feasibility. The strategy that would best meet all criteria was the jet fan option. The recommended system consists of jet fans in the tunnels generally located 50 meters from each end of the stations. The jet fan operating mode would be dependent on the location of the fire within the station.

CFD ANALYSIS

A CFD analysis was performed using a commercially available CFD software, run on a DEC Alpha workstation. For the last five years, the SES program has been used in conjunction with CFD to simulate fire emergencies in subway stations where three-dimensional modeling is more app opriate. While CFD has the capability to model more complex station geometry, the SES program provides the fundamental boundary conditions necessa y for the CFD analysis. This coupling of computer tools has helped subway ventilation engineers to solve problems and analyze situations where conventional techniques would have failed or been grossly inadequate.

CFD simulations were performed to evaluate the station conditions resulting from a fire on board a train stopped in a station with and without mechanical vent lation. For natural ventilation (i.e., no mechanical ventilation), ambient pressure was assumed at all flow boundaries. For mechanical ventilation, simulations were performed to determine the airflow boundary conditions at the ends of the station. Ambient pressure conditions were used at station entrances.

Two stations were selected for the simulations:

Medrano Station is a cut-and-cover station with side platforms and no mezzanine. The station is about 130 m long, 33 m wide, and 6 m high. The station has a total of four exits. Each platform has two exits to outside ambient. Figure 1 shows the general layout of the station. The computational grid used for this station is about 84,000 cells. The grid consists of 117 cells in the longitudinal x-direction, 20 cells in the vertical y-direction, and 36 cells in the lateral z-direction. The number of cells is based on previous project experience with consideration of the accuracy required in the study.

Pueyrredon Station is a bored tunnel station with a mezzanine above the two side platforms. The station is about 130 m long, 21 m wide, and 10 m high. Two escalators and one stairway connect each platform to the mezzanine. This station has five exits. Figure 2 shows the general layout of the station. The computational grid used for this station was about 85,000 cells. The grid consists of 131 cells in the longitudinal x- irection, 21 cells in the vertical y-direction, and 31 cells in the lateral z-direction.

Two fire scenarios were considered: (1) a fire at either end of the station beyond the last exit or staircase and (2) a fire

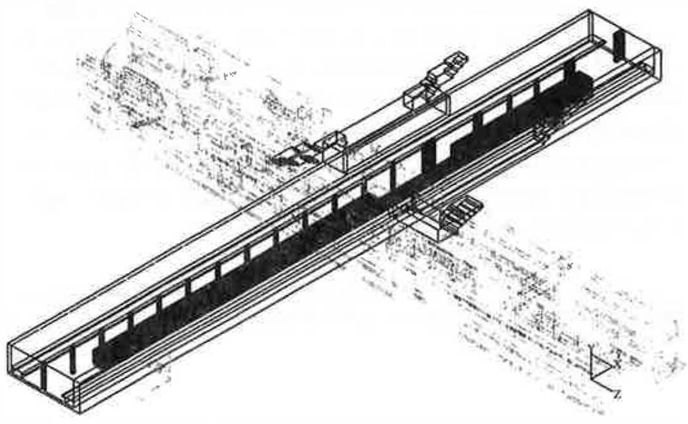

Figure 1 Medrano station layout. Grid (117 × 20 × 36).

between exits or staircases. The first scenario required the ventilation system to push smoke and hot gases toward the tunnel, or in the direction opposite to that of the evacuating passengers. The second scenario required the ventilation system to force outside air through the station exits or stairways, thus maintaining the evacuation paths free of smoke and hot gases. The latter scenario is considered the worse case of the two because of the proximity of the fire to the exits or staircases. CFD simulations, therefore, focused on the second scenario.

RESULTS

A total of four steady-state CFD simulations were performed, two for each station (Medrano and Pueyrredon). The first simulation was used to evaluate the station conditions when no mechanical ventilation is used (natural ventilation). The second simulation evaluated the effectiveness of the jet fan ventilation system. The jet fan capacities used were those that satisfied the emergency requirements in the tunnel sections adjoining these stations. Eight 630 mm diameter jet fans were simulated per station. The selected fan size is the maximum that can be accommodated without modifications to the tunnel structure. The minimum static thrust per fan varies depending on the tunnel configuration. For Medrano and Pueyrredon stations, the static thrust per fan is 390 N and 290 N, respectively. In all CFD simulations, moving trains were not simulated and the fire size was maintained the same.

Medrano Station

A train fire is located between the two entranceways at Medrano Station. Although with natural ventilation the air temperatures in the evacuation paths would not exceed 60°C (Figure 3), hot gases would rise to the entranceways due to natural buoyant effects resulting from the temperature difference between the system and outside air. Passengers would be exposed to smoke/hot gases. With jet fans operating, hot gases are pulled toward the tunnels on both sides of the fire. Outside air is being drawn into the station from both entranceways (Figure 4). An evacuation path can be maintained under 60°C.

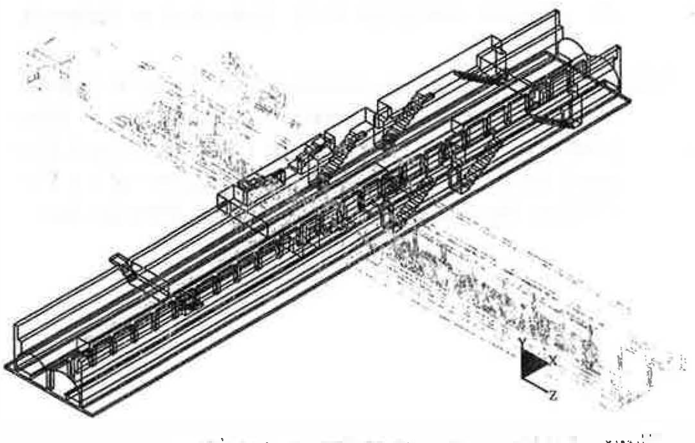

Figure 2 Pueyrredon station layout. Grid (131 × 21 × 31).

Pueyrredon Station

At Pueyrredon Station (Figure 2), a train fire is located between the two entranceways near the quarter point of the platform. With natural ventilation, hot gases will contaminate all staircases and entranceways (Figure 5). In the staircase closest to the fire site, air temperature will be as high as 100°C. In addition, air temperature at the mezzanine will exceed 60°C. An evacuation path will not be maintained under natural ventilation. With the operation of jet fans, however, the hot gases will be contained to the platform level (Figure 6). Outside air is being drawn into the station through the entranceways. All staircases and exits will be maintained at temperatures below 40°C.

For both simulations for mechanical ventilation, the predicted air velocity in the path of evacuation will not exceed 11 m/s for passenger evacuation, but this is not shown in the figures.

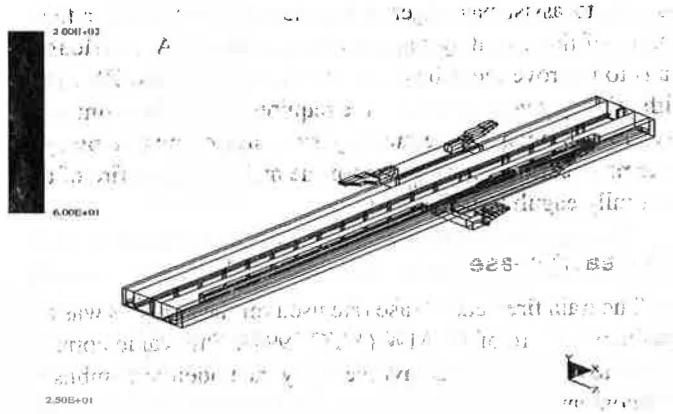

Figure 3 Medrano station natural ventilation. Temperature: °C.

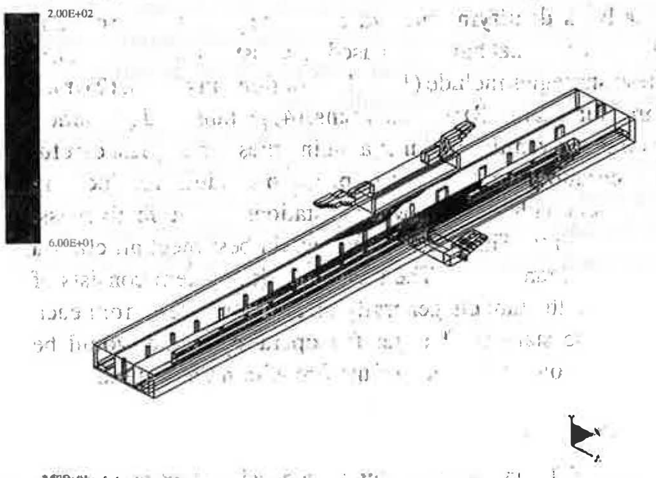

Figure 4 Medrano station mechanical ventilation. Temperature: °C.

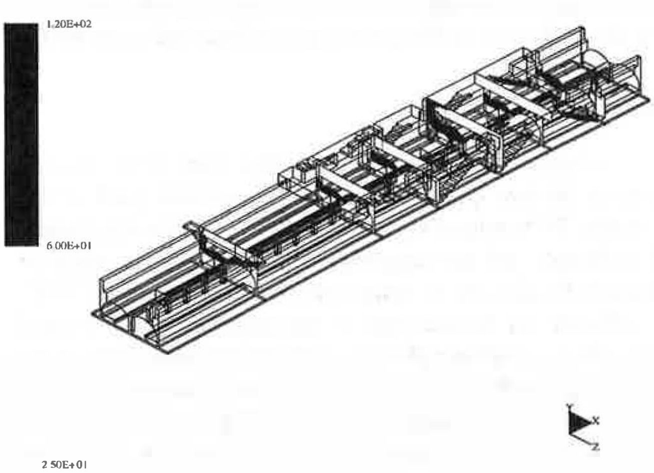

Figure 5 *Pueyrredon station natural ventilation. Temperature: °C.*

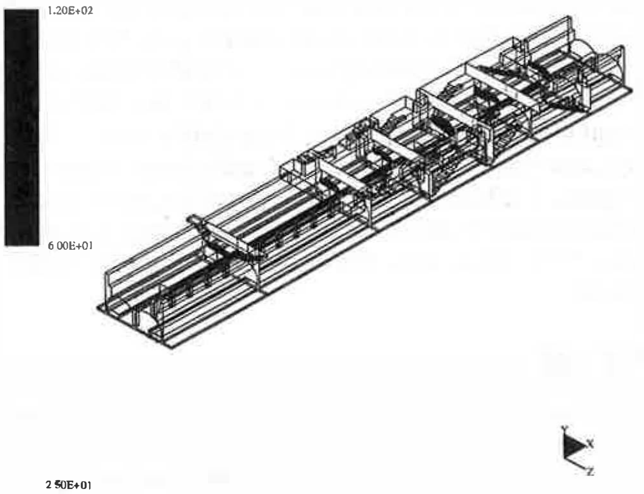

Figure 6 *Pueyrredon station mechanical ventilation. Temperature: °C.*

CONCLUSIONS

The analysis showed that natural ventilation would be insufficient to prevent the buildup of hot gases at the platform and mezzanine areas during a station fire and would not maintain acceptable conditions for evacuating passengers. The tunnel emergency ventilation system, using jet fans on both sides of the station, would effectively control smoke spread during a station fire and maintain acceptable conditions for evacuating passengers.

The simulations showed that for a fire between exits or staircases, operating the jet fan system would draw in outside air through exits or stairways, thus maintaining an evacuation path free of hot gases. For a fire at either end of the station beyond the last exit or staircase, the jet fans should be operated in the same direction to generate longitudinal airflow in the direction opposite to the evacuation path.

The jet fan system would be a viable and cost-effective alternative that will meet the established criteria for emergency ventilation in existing tunnels and stations. Although this system has some inherent limitations with regard to smoke purge, it would provide an increased level of safety in the existing subway at a reasonable cost.

CFD can be used in conjunction with SES simulations to provide some insight regarding station fires and to determine the most appropriate ventilation scheme to control the spread of fire and to provide a progressively better and safer evacuation path in the station. However, very few CFD codes have been validated against fire experiments for stations and tunnels. Phase IV of the Memorial Tunnel Fire Ventilation Test Program (MHD/FHA 1995) is correlating CFD computer codes using observations of about 100 actual tunnel fires monitored in the tunnel. This work will facilitate the future understanding and prediction of tunnel fire behavior and associated smoke/temperature migration.

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