

Transverse Ventilation System of the Holland Tunnel Evaluated and Operated in Semitransverse Mode

N. LESSER, F. HOROWITZ, AND K. KING

The Holland Tunnel, which has a fully transverse ventilation system, had to have its ceiling removed because of concrete deterioration. For more than a year before the installation of a new ceiling, vehicular traffic would continue, and the ventilation system would operate in a semitransverse mode. Evaluations were conducted to ascertain the capability of the ventilation system to maintain an acceptable environment during normal vehicular usage and in the event of fire. These evaluations included computations for varying traffic patterns and actual fire testing.

Once described as the eighth wonder of the world, the Holland Tunnel opened for use in 1927 and was designated a National Historic Civil and Mechanical Engineering Landmark on May 2, 1984. One of the reasons for conferring landmark status on the tunnel was an unprecedented ventilation system that made possible the longest underwater vehicular tunnel of the time. The tunnel consists of two independent tubes, each with two traffic lanes, approximately 8,500 ft long.

Because of deterioration after nearly 60 years of operation, the ceiling, which forms a basic element of the ventilation system, had to be replaced. However, the tunnel tubes, which are a vital link in commuting and trucking routes in and out of New York City, could not be shut down for an extended period. All work—removals, measurements, and new construction—would have to be done at night and the tunnel tube restored for traffic use each morning. The simplest way to implement such a staging requirement is to completely remove the existing ceiling, take measurements, and then prefabricate and install sections. This procedure would result in the tunnel tubes being without a ceiling for more than a year.

Evaluations and field tests were conducted to determine whether, without a ceiling, the ventilation system could

- Maintain environmentally acceptable conditions under normal traffic patterns and
- Control smoke during fire emergency conditions.

The evaluations included computer simulations of contaminant levels that would result from varying traffic patterns, critical velocity computations for smoke control, and in situ fire tests.

EXISTING SYSTEM

The existing ventilation system for the Holland Tunnel was designed as a fully transverse system. The ventilation system is divided into sections along the length of the tunnel; each supply and exhaust section is served by multiple fans; each fan is capable of operation at three or four speeds.

Outside air is supplied from the chamber under the roadway through openings spaced approximately 15 ft apart along both curbs. Vitiated air is exhausted through ports spaced 15 ft apart in the original ceiling. The ports are centered above each lane of traffic. The exhaust ports are sized to balance air quantities, and, as a result, rather small ports are located near ventilation building shafts. Figure 1 shows a longitudinal cross section of the tunnel tubes and the various ventilation sections and ventilation buildings. Figure 2 shows a transverse cross section. The vitiated air is monitored for contaminant levels in each ventilation section, and the appropriate number of fans is manually set at the speed required to maintain safe contaminant levels.

The system has proven to be fully capable of controlling contaminant levels under normal operating conditions including peak traffic flows and traffic stoppages.

During fire emergencies, when the smoke and heat generated are within the moderate range—this includes a burning automobile or even a truck that is not carrying a highly flammable or “smokey” load—the ventilation system is reconfigured to control the smoke and heat and provide life-supporting uncontaminated air to vehicle occupants and fire fighters within the tunnel. Maximum exhaust capacity is used in the section that contains the fire, and supply is provided in all sections. (Highly flammable cargo is not allowed in the tunnel.)

The basic traffic pattern is eastbound in the south two-lane tube and westbound in the north two-lane tube. However, at times, to facilitate maintenance, two-way traffic is implemented in a tube. When a two-way traffic pattern is in effect, the ventilation system serves in the normal manner.

INTERIM SYSTEM

With the ceiling removed, the ventilation system is operated in a semitransverse pattern. Computations, using the FHWA TUNVEN computer program, were performed to evaluate the resulting contaminant levels. The TUNVEN program permits the solution of coupled, one-dimensional, steady-state tunnel aerodynamics and advection equations to obtain longitudinal

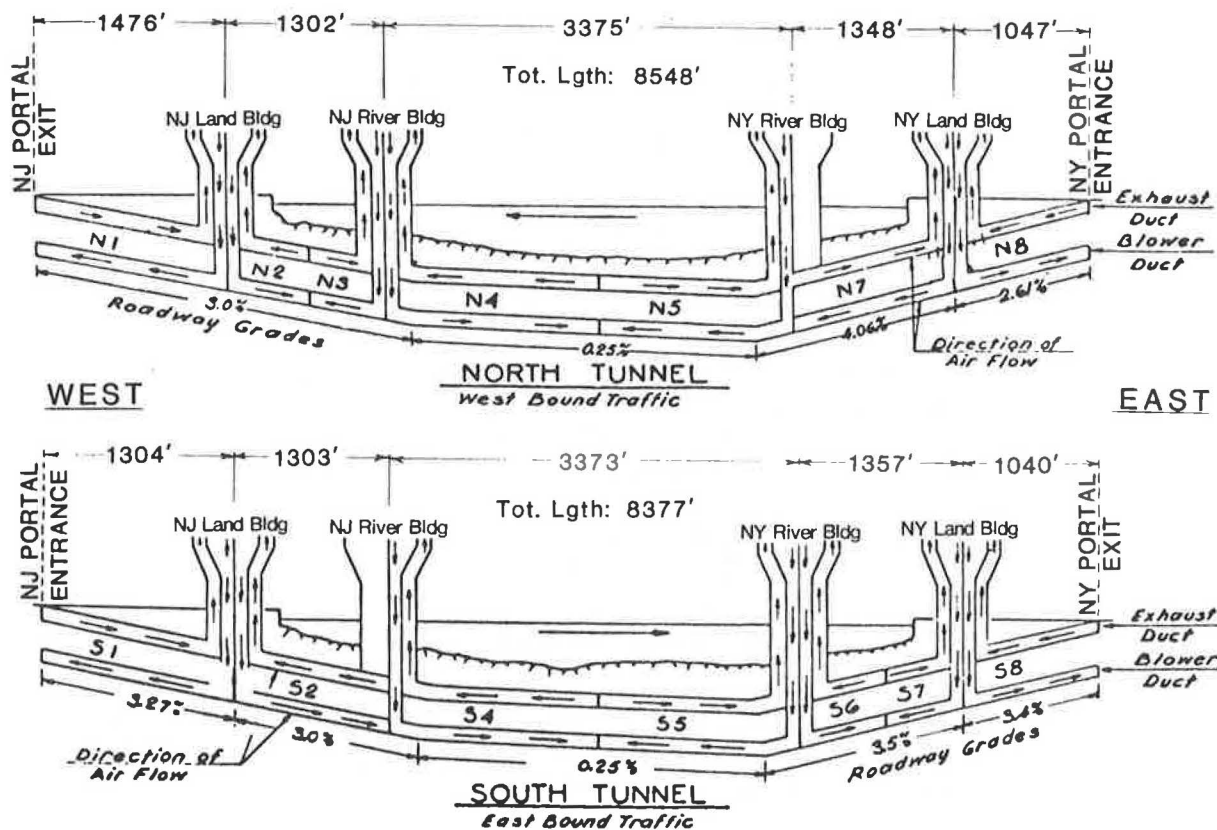


FIGURE 1 Longitudinal cross section of Holland Tunnel tubes.

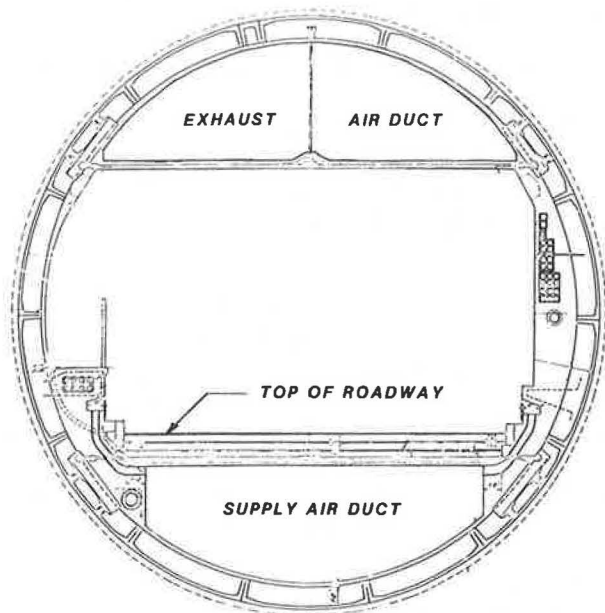


FIGURE 2 Transverse cross section of Holland Tunnel tubes.

air velocities and pollutant concentrations for a given tunnel design, traffic load, and ventilation rate. The program can be used to determine ventilation requirements for natural, semi-transverse, and fully transverse ventilation systems. In this instance the ventilation rates were fixed, and the adequacy of these rates to control contaminant levels was sought. On the basis of the results, which predicted satisfactory contaminant

levels, it was decided to remove the existing ceiling in its entirety. Segment-by-segment removal and replacement would not be pursued.

Figure 3 shows measured values for the fully transverse and the semitransverse configurations under heavy traffic conditions.

During a fire emergency, the ability of the ventilation system to mitigate the risks will depend, as it does with the present ceiling, on the severity of the fire. The ventilation system would be reconfigured to control smoke movement in a specific direction. This presumes that traffic is one way and that all vehicles downstream of the incident have left the tunnel. A specific reconfiguration was developed for each tunnel tube section. The underlying principle was to exhaust downstream (traffic flow) of the ventilation section containing the fire, supply air upstream of that section, and provide minimal air supply in the fire section and all downstream sections.

Longitudinal velocities of the air should be sufficient to prevent back-laying or bidirectional air flow (smoke-laden air moving above uncontaminated air moving in the opposite direction) and to be low enough in velocity to minimize turbulence. This critical longitudinal velocity was initially determined through calculations using the UMTA Subway Environment Simulation (SES) computer program. The intent is to keep, for as long as possible, the smoke-laden air, which is moving to the exhaust shaft, in the upper cross section of the tunnel. The air supplied to the fire section and all sections downstream is intended to support the desired stratification and to provide life-sustaining air at lower levels for fire-fighting personnel. Fire department vehicles would proceed to the fire

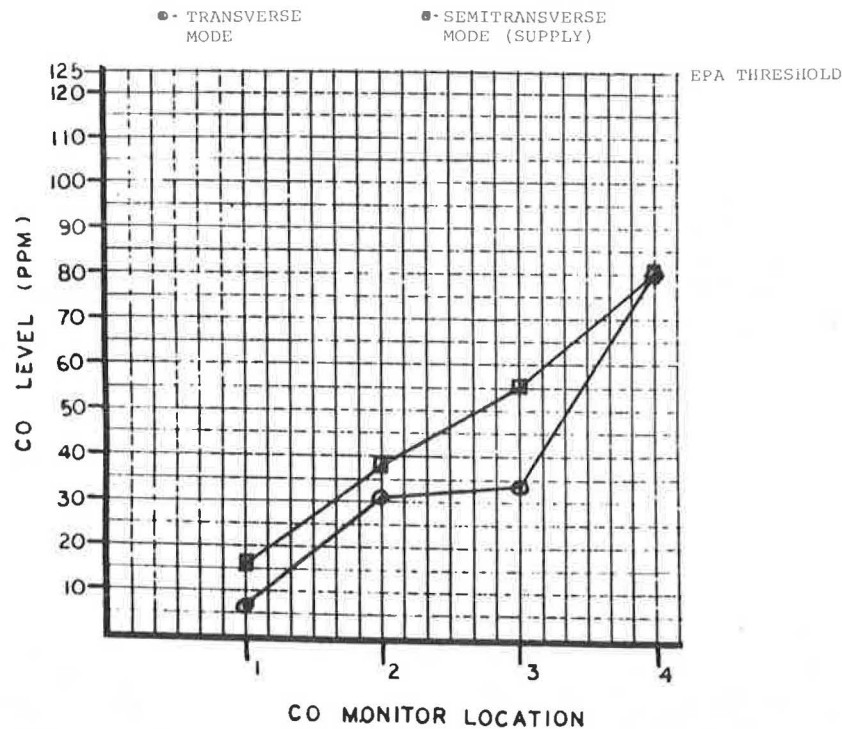


FIGURE 3 Comparison of CO levels of transverse configuration with those of semitransverse configuration under heavy traffic.

from the downstream direction, moving counter to the smoke exhaust flow. Maintaining the stratification of smoke-laden air for as long as possible is essential to providing acceptable visibility for fire department access.

There would be obvious advantages to permitting two-way traffic in one two-lane tunnel tube while the other tube is out of service for construction activity. However, the emergency ventilation approach just described for fire conditions is considered inadequate for two-way traffic. Should a major fire develop with two-way traffic, vehicles could have great difficulty exiting the tunnel in both directions. Reconfiguring the ventilation system in an attempt to control movement of smoke and heat in one direction or another would create the risk that trapped vehicles and their occupants would be enveloped in smoke. This factor, coupled with the possibility of having a more serious accident with two-way traffic, increases the life safety risk significantly. The risk could be mitigated somewhat by limiting traffic speed, stationing additional traffic control personnel within the tunnel, and substantially increasing cargo inspections or precluding truck traffic. However, short of precluding truck traffic, these measures would not modify the level of risk appreciably, and such a preclusion is impractical. Therefore the decision was made to not permit two-way traffic within a single tube. Diversion to the Lincoln Tunnel would be used instead.

FIRE TESTS

Because it was decided on rather short notice to field test the emergency reconfiguration of the ventilation systems, there was not time to instrument the tunnel.

Four configurations were tested in an attempt to evaluate the following parameters:

- Maximum supply upstream and maximum exhaust downstream,
- Minimum supply and exhaust,
- Maximum supply upstream and downstream and maximum exhaust downstream, and
- Moderate supply upstream and moderate exhaust and supply downstream.

The tests were conducted in ventilation Section S5 in the south tube. The distance from the test fire to the nearest downstream ventilation building was approximately 1,000 ft. The fire and smoke were created by the combustion of diesel fuel in three open half-sections of 55-gallon drums. The fire was estimated at 2 million Btu/hr per drum or approximately 6 million Btu/hr total. The critical velocity for a 2 million Btu/hr fire was calculated to be 250 ft/min; for 8 million Btu/hr, 400 ft/min; and for 30 million Btu/hr, 600 ft/min.

The proposed fan configuration for Test Run 1 is given in Table 1 (refer also to Figure 1).

In Test 1, the maximum air quantity that the installation was capable of supplying was provided in Ventilation Sections S1 and S2, and almost the maximum was provided in Section S4 with no exhaust. Minimum outside air was supplied in Sections S5, S6, S7, and S8. Maximum available exhaust was used in Section S5 and near maximum was used in the other downstream sections (S6, S7, and S8). The intent was to create high air velocities at the fire location and, as previously noted, prevent back-layering. The resulting effect was an entirely smoke-free tunnel upstream with smoke moving downstream

TABLE 1 EMERGENCY FAN CONFIGURATION OF SOUTH TUBE SECTION S5 (Test 1)

Ventilation Section	Exhaust		Supply	
	Fan/Speed	ft ³ /min	Fan/Speed	ft ³ /min
S1	None		3/4	260,000
S2	None		3/4	180,000
S4	None		3/3	325,000
S5 ^a	3/4	500,000	1/1	100,000
S6	3/2	245,000	1/1	50,000
S7	3/3	180,000	1/1	50,000
S8	3/2	190,000	1/1	75,000

^aLocation of fire.

within the upper one-third of the tunnel tube cross section for approximately 400 to 500 ft and then dropping to the roadway. After the smoke dropped, visibility within the tube was poor. As a result, there was inadequate visibility for fire department vehicles to proceed safely to the fire; therefore this reconfiguration was considered unacceptable.

Test 2 (Table 2), the minimum air scheme, was an attempt to minimize turbulence to the fullest extent possible. Table 2 gives the fan configuration for this reconfiguration. Smoke moved downstream in the upper part of the tube cross section at approximately 250 ft/min; however, smoke also moved upstream and dropped to the roadway. The resulting back-layering and lack of control eliminated this approach.

TABLE 2 EMERGENCY FAN CONFIGURATION OF SOUTH TUBE SECTION S5 (Test 2)

Ventilation Section	Exhaust		Supply	
	Fan/Speed	ft ³ /min	Fan/Speed	ft ³ /min
S1	None		1/1	50,000
S2	None		1/1	50,000
S4	None		1/1	90,000
S5 ^a	1/1	100,000	1/3	180,000
S6	1/1	60,000	1/1	50,000
S7	1/1	50,000	1/1	50,000
S8	1/1	75,000	1/1	75,000

^aLocation of fire.

Test 3, as indicated in Table 3, represented a configuration in which a high air capacity was supplied downstream of the fire as well as upstream. Also, high exhaust capacity was maintained downstream of the fire. The idea was to dilute and purge the smoke-laden air so as to allow at least 100 ft of visibility downstream. This approach was not successful because the quantity of air supplied was insufficient to dilute the smoke-laden air, which quickly cooled and dropped to the roadway. Visibility was not adequate.

In Test 4 (Table 4) a moderate quantity of outside air was supplied upstream of the fire in Sections S1, S2, and S4. In Section S5, the section with the fire, a moderate supply was maintained with the exhaust twice the amount of supply. In the more remote downstream sections minimum supply and exhaust were maintained. The velocity created within the fire section (S5) was approximately 500 ft/min.

TABLE 3 EMERGENCY FAN CONFIGURATION OF SOUTH TUBE SECTION S5 (Test 3)

Ventilation Section	Exhaust		Supply	
	Fan/Speed	ft ³ /min	Fan/Speed	ft ³ /min
S1	None		3/4	24,000
S2	None		3/4	180,000
S4	None		3/4	400,000
S5 ^a	2/4	400,000	3/4	450,000
S6	3/2	250,000	3/4	200,000
S7	3/4	250,000	3/4	200,000
S8	1/1	75,000	1/1	75,000

^aLocation of fire.

TABLE 4 EMERGENCY FAN CONFIGURATION OF SOUTH TUBE SECTION S5 (Test 4)

Ventilation Section	Exhaust		Supply	
	Fan/Speed	ft ³ /min	Fan/Speed	ft ³ /min
S1	None		3/3	240,000
S2	None		3/3	180,000
S4	None		3/3	450,000
S5 ^a	2/4	400,000	3/2	200,000
S6	1/1	60,000	1/1	50,000
S7	1/1	50,000	1/1	50,000
S8	1/1	75,000	1/1	75,000

^aLocation of fire.

Upstream was maintained smoke free. Smoke moved downstream within the upper cross section of the tube for approximately 450 ft, then a portion started to drop to the roadway. However, the air supply was sufficient to dilute the smoke, and adequate visibility was maintained for 250 ft. Further downstream, in Sections S6, S7, and S8, there was minimal smoke. Fire department vehicles drove to the fire location through the downstream sections without difficulty. (The fire department participated in the final testing.)

On the basis of the ventilation pattern created in Test 4, fan configurations for fires in all possible tunnel locations were developed, and operating personnel received detailed instructions for implementing such configurations in the event of an emergency.

The following points summarize the results of the fire tests.

- It was not possible to establish stratified flow of smoke in the upper tube cross section for an extended distance and also have a smoke-free condition upstream of the fire.
- Using the maximum ventilation capacity to dilute the smoke to maintain adequate visibility was not successful.
- Optimum conditions resulted from a ventilation reconfiguration that provided sufficient air velocity to prevent back-layering and, at the same time, create stratified smoke flow for a limited downstream distance. A certain portion of the smoke-laden air then dropped as a result of cooling and turbulence. However, the moderate quantity of air supplied diluted the smoke-laden air enough to provide 250 ft of adequate visibility.

NEW CEILING EXHAUST PORTS

A new ceiling will be placed in the tunnel tubes. This ceiling will, in effect, return the ventilation system to fully transverse. To improve the ability of the system to mitigate adverse conditions during a fire emergency, the exhaust ports will be as large

(6 ft × 1 ft) as they can be and still maintain the structural adequacy of the precast concrete panels that form the new ceiling.

To permit balancing exhaust quantities, fusible damper plates, which would melt away under fire conditions, are being used. It is anticipated that greater smoke removal capacity in the vicinity of a fire will result.