Memorial Tunnel Fire Test Program

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Exposure to smoke generated by fires within highway tunnels is a critical safety issue in the United States, where no standards have been established for smoke-control ventilation in such structures. The Massachusetts Highway Department conducted the Memorial Tunnel Fire Test Program to develop a data base that gives tunnel designers and operators a proven means to determine the ventilation rate and system configuration that will provide the most effective smoke control during a tunnel fire. The test results are applicable to the design of new tunnels and the optimal configuration management of ventilation in existing tunnels.

PROBLEM

Smoke-control ventilation has two purposes: to protect life by allowing evacuation of tunnels and, if possible, to give fire-fighting personnel a clear path to the site of the fire. Designs for smoke-control ventilation have been created on the basis of theoretical computations or empirical rules of thumb instead of on full-scale instrumented tests. Consequently, the design approach to detection, control, and suppression of fire and smoke within highway tunnels has become a controversial issue among tunnel engineers, tunnel operators, and fire fighters. To resolve this issue, investigations of ventilation strategies and their effectiveness in full-scale fire tests have been undertaken as part of the largest underground highway project ever initiated in the United States: the $8 billion Boston Central Artery/Tunnel (CA/T) project, funded by the Federal Highway Administration and the Massachusetts Highway Department.

SOLUTION

A test facility was constructed at Memorial Tunnel, a two-lane, 854-meter (2,802-foot), decommissioned highway structure that formerly was part of the West Virginia Turnpike. The existing ventilation equipment was removed to allow installation of new variable-speed, reversible, axial-flow, central-ventilation fans. The equipment rooms were modified to accommodate the ventilation components needed for supply or exhaust operation from both ends of the tunnel. Six fans with a supply or exhaust capacity of 94.4 cubic meters per minute (3,334 cubic feet per minute) were installed: three each in the modified north and south portal fan rooms. The existing overhead air duct was split into longitudinal sections to serve as supply and exhaust ducts, and a mid-tunnel duct bulkhead was placed in a position to allow a two-zone ventilation operation. High-temperature insulation was applied to structural elements and support systems.

Fires with heat-release rates ranging from 10 to 100 megawatts were produced. The fires were generated in four floor-level steel pans in which a metered flow of fuel oil was floated on top of a layer of water.

The ventilation systems were configured and evaluated in the context of varying flow and heat-release rates, with one or two zones of ventilation, in accordance with a test plan developed in cooperation with the American Society of Heating, Refrigerating, and Air-Conditioning Engineers. Six configurations were tested: transverse ventilation, partial transverse ventilation, ventilation with single-point extraction, transverse ventilation with oversized exhaust ports, natural ventilation, and longitudinal ventilation with jet fans. In full transverse ventilation, a configuration common in the United States, air is supplied at the roadway level and extracted through ceiling ports. In longitudinal ventilation with jet fans, a configuration used worldwide, air is pushed from portal to portal along the tunnel.

Instruments monitored air temperature, air velocity, and gas concentrations during tests. Two towers outside the portals were equipped with instruments to monitor meteorological variables. In total, there were approximately 1,450 instrumentation sensing points. Approximately 4 million observations were recorded during a typical fire test, which lasted as long as 45 minutes.

By September 1993, 100 tests had been completed. The results were made available on CD-ROM for use in the development of tunnel-ventilation design and emergency procedures.

Application

The cost of different types of ventilation systems varies significantly. Safety is paramount; however, when more than one ventilation configuration offers an acceptable level of fire safety, the life-cycle cost of a project should be addressed to identify the best option.

Results of the Memorial Tunnel fire tests have been used to increase the cost-effectiveness of fire-safety measures. The Boston Fire Department agreed to change required ceiling-panel fire ratings throughout the 60 lane-kilometers (38 lane-miles) of tunnels along the Central Artery/Tunnel. In addition, the Federal Highway Administration lifted its moratorium on the use of jet fans for longitudinal ventilation in tunnels similar to the Memorial Tunnel.

Benefits

The Memorial Tunnel Fire Test Program has benefited the Central Artery/Tunnel project in two ways. First, the program led to ceiling-material design changes, saving $20 million in construction costs without compromising safety. Second, it led to the modification of the CA/T design to provide for jet-fan use, saving $25 million through the reduction of cross-sectional envelopes and the elimination of air ducts and ventilation fans.

The biggest payoff, in construction and operating cost savings and possibly in lives saved, is likely to be realized as tunnel designers around the world begin to take advantage of the data produced by the Memorial Tunnel fire tests. The use of longitudinal ventilation, made possible by the lifting of the moratorium on the use of jet fans, has already resulted in significant cost savings for three dual-bore tunnel projects in the United States. The estimated savings range from $3,000 to $5,000 per meter of structure. Operating and maintenance costs for these tunnels have also been reduced.

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MASSACHUSETTS HIGHWAY DEPARTMENT

View of south portal of fire-test facility constructed at Memorial Tunnel, formerly part of the West Virginia Turnpike.

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Suggestions for "Research Pays Off" topics are welcome. Contact G. P. Jayaprakash, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418 (telephone 202-334-2952; e-mail gjayapra@nas.edu).