Development of Tunnel Operations and Preventive Maintenance in Quebec

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In the Montreal area, 30 000 ft of expressway lanes run through tunnels, two of which are remarkable by their size and design. These tunnels are the Louis-Hippolyte-Lafontaine Tunnel, which runs under the St. Lawrence River, and the Ville-Marie Tunnel, which is situated in the very heart of the City of Montreal. Both of these tunnels are located on Autoroute 20, which forms part of the Trans-Canada Highway. The implementation of these tunnels in Quebec and their development in operations and preventive maintenance (i.e., operations, electromechanical installations, communications, closed-circuit monitoring, and all other work related to operating tunnels) are discussed.

The two most important expressway tunnels in the Province of Québec are located in the Montreal area. These are the Louis-Hippolyte-Lafontaine Tunnel and the Ville-Marie Tunnel. Both are part of the Trans-Canada Highway (Autoroute 20).

The Louis-Hippolyte-Lafontaine Tunnel, which passes under the St. Lawrence River, was the first to be completed. The entire project, including approaches, interchanges, and the tunnel itself, took less than four years to build (July 1963 to March 1967). This is truly an underwater gallery, which measures 1.12 miles in length and has two three-lane tubes. In addition, the central section is made up of seven independent prestressed concrete elements that were prefabricated in dry dock, towed to the site, and then submerged.

The two end sections of the tunnel--one measuring 530 ft on the north shore of the St. Lawrence and the other 1480 ft on the shore of Ile Charron--were both built on site. Two ventilation towers form part of this huge complex. The one located on the north side is used as the operations and monitoring center for the Lafontaine Tunnel.

The Ville-Marie Tunnel was built between 1971 and 1974 and runs in an east-west direction under the very heart of Montreal for a distance of 1.06 miles. There are two main tubes, each with three to five traffic lanes, but the principal feature of this tunnel is its many underground connecting points (the University Street interchange being the most important).

The Ville-Marie Tunnel complex has five ventilation towers that are spaced about 1000-1500 ft apart. One of the towers--tower number 9--which is located at the corner of Busby and Viger Streets, serves as the operations and monitoring center for the tunnel.

In addition, following a government decision to extend the Ville-Marie expressway, another tunnel is currently under construction. This extension, the future Viger Tunnel, was necessary in order to preserve a green space--the Viger Park. This new tunnel section, which will be 1500 ft in length, will have underground ventilation towers in order to comply with City of Montreal town planning requirements. They will rise approximately 16 ft above ground level and will blend in with the environment. The cost of the Viger Tunnel will be $35 million.

TRAFFIC MONITORING

In order to obtain factual statistics on the number of vehicles traveling in each lane of the tunnel, the Ville-Marie Tunnel builders installed capsules that were supposed to provide a vehicle count. It was soon evident, however, that use of such capsules was unsuitable for underground roadways, as the traffic readings were incorrect. The capsules have since been replaced with a magnetic-tune-loop system similar to that used in the Lafontaine Tunnel, which has been reliable up to now.

Because they are located in a highly urban area, the Lafontaine and Ville-Marie Tunnels take care of a great deal of traffic. The Lafontaine Tunnel's summer daily average traffic is 96 000 vehicles. One can readily imagine that there is a high risk of an incident occurring in these tunnels. Thus, the importance of adequate monitoring is warranted.

With closed-circuit television in the control room, traffic controllers can monitor inside the tunnel on a full and constant basis. In fact, the surveillance and control equipment is installed in such a way that when a vehicle enters the tunnel, the controller can follow its progress without ever losing sight of it until it leaves the tunnel.

By using this type of monitoring, it is possible to detect the slightest incident occurring inside the tunnel and to correct it without delay. As soon as an incident is identified, whether it be a fire, an accident, or a breakdown, the controller uses the overhead traffic lights to direct the flow of traffic. For instance, the red light is switched on above the lane where the incident has occurred and its traffic is diverted to adjacent lanes by means of flashing amber lights.

Experience has shown that in such circumstances, Lafontaine Tunnel users almost always obey traffic light signals, whereas motorists who use the Ville-Marie Tunnel more often wait to see what has happened before reacting and moving over to adjacent lanes. Therefore, there is reason to suppose that the Ville-Marie Tunnel alignment changes the motorist's field of vision in such a way that, under certain angles, the traffic light on the driver's right is in his or her direct line of vision, thereby resulting in a slow reaction time when an incident occurs.

COMMUNICATIONS

Now, let us turn back to the controller. Once the flow of traffic is back to normal by means of the traffic lights, the controller must take another action, depending on the type of incident. In the case of a stalled vehicle, he or she calls the towing services. I should point out at this time that for all the Montreal area expressways, including the tunnels, the Ministère des Transports has turned over the job of providing breakdown services to private firms. It is up to the controller to give all necessary information to the towing services, such as the exact location of the breakdown and the type of vehicle. Statistics show that it takes an average of 12 min to respond in the case of both tunnels. Moreover, during rush hours a tow truck is on standby at the entrance to the Lafontaine Tunnel. In fact, during these crucial moments, the tow truck's response time is approximately 5 min.

If an accident occurs, the controller must notify the police authorities and, if necessary, the ambulance services. If there is a fire, the controller sets in motion fire-fighting arrangements made with the fire department of the City of Montreal. Until the arrival of the firemen on the scene, tunnel employees operate such fire-fighting equipment as fire extinguishers and fire hoses located in built-in cabinets placed some 250-300 ft apart along the tunnel walls. The fire fighters can reach the scene of the fire by driving through the tunnel against the flow of traffic when assisted by police officers.

Another of the controller's duties is reversing the ventilation system in the affected section and operate it so that the smoke and harmful fumes can escape without causing discomfort to motorists and without fanning the fire. Fortunately, there have been no major fires in the Lafontaine and Ville-Marie Tunnels since they have opened to traffic. Only a few cars have caught fire in the Lafontaine Tunnel.

An act, which has been in force since 1974 and prohibits the transportation of dangerous commodities (such as flammable and nonflammable compressed gas, explosives, and oxidizing, radioactive, and corrosive materials) through the tunnels at all times, has greatly reduced the possibility of major fires occurring in the two tunnels. The Ministère des Transport's highway patrols exercise tight control in order to prevent, as much as possible, the transportation of dangerous commodities. Since 1975, they have handed out more than 1100 violation tickets to truckers who carried such cargo through the two tunnels.

Without proper telephone communications with the fire and police departments as well as with breakdown services, the controllers would be unable to cope with the various situations without delay. A telephone service is also available to motorists in trouble in the tunnel. Telephones that provide direct contact with the control center are spaced between 150 and 300 ft apart.

At the Lafontaine Tunnel, antennas provide radio communications between the control room and maintenance vehicles. Due to the different geometry of the lanes in the Ville-Marie Tunnel, it was necessary to install a radian coaxial cable to provide radio contact, without cut-offs, between the control center and maintenance vehicles. This is a community cable network used mainly by the various police and fire departments. When motorists must be evacuated through emergency hallways, the controller can give instructions through a loudspeaker system.

MAINTENANCE

Cleaning the tunnel walls is one of the principal maintenance activities. The department has a brush truck specially designed to do the job, as well as two rinse trucks. The work is done at night, as is most other maintenance work. The tunnels are washed periodically.

Top priority is given to maintaining the lighting system, which is of prime importance inside a tunnel. It is therefore necessary to replace fluorescent lamps at the tunnel entrance about every two years, since this is their approximate effective life span. A truck equipped with a hydraulic platform is used to change the lamps. Relamping inside the tunnel is done every three years, except in the case of the Ville-Marie Tunnel, where lamps were only changed in 1979, five years after its opening. The method of a periodical complete lamp change is preferred for cost reasons. The difference in the frequency of this operation in the two tunnels is due to the higher density of traffic in the Lafontaine Tunnel and, as a result, the fluorescent lamp protective coverings get dirty much more quickly and cause reduced visibility.

With regard to the pavement in both tunnels, it requires about the same maintenance as any surface expressway. The water drainage system is checked and maintained regularly. Catch basins are inspected every three months. In the Ville-Marie Tunnel, scourers are used to clean the drain pipes in the fall.

The water distribution line and the gutter expansion joints are heated by electric cables. Plastic-covered nonflexible copper-sheathed cables are used in the Lafontaine Tunnel, whereas neoprene-sheathed bytil-rubber heating cables are installed in the Ville-Marie Tunnel. These proved to be less resistant than expected and, in some cases, were replaced with the same type used in the Lafontaine Tunnel.

Preventive maintenance is possible with the cardex system set up to record inspections made on the various pieces of equipment in both tunnels. Telecontrolling, telemetering, and telesurveillance of mechanical and electrical parts of the complex are carried out by means of a computer-operated system installed in the Ville-Marie Tunnel. Therefore, it is quick and easy to detect defects or faults in a system, as any abnormality found by the computer immediately appears on a cathodic screen and its principal coordinates are transmitted by printer. A data sheet drawn up by the controller is then forwarded to the person in charge of maintenance. In both tunnels, maintenance of sophisticated equipment, such as motor generator sets, closed-circuit televisions, elevators, the 12-kV electric substations, pumps, ventilation motors, control panels, noninterruption units, and the computer, is done with the help of private firms.

Maintenance of the Ville-Marie and Lafontaine Tunnels is not without its problems because of the numerous mechanical and electrical installations and also on account of the severity of the weather. Some of the problems encountered are rusting of electric conduits, short-circuiting in the alarm wiring, corrosion of fans, water infiltration, and machines jammed by dirt.

Other problems are design related. In the Lafontaine Tunnel, space for easy access to the fans by work crews was forgotten, thereby making it difficult for the crews to handle spare parts when making repairs.

And, of course, there are the more complex problems, such as the lack of follow-up service by sophisticated equipment suppliers and sometimes difficulty in obtaining needed repair parts. One such problem was with regard to the wiring and electric conduits, which were exposed to severe cold in some places. It was decided to replace them with polyvinyl chloride (PVC) conduits and connections, which are more resistant to dampness than galvanized steel. Weatherproof wiring is also used.

VENTILATION SYSTEM

Due to the different configurations of the tunnels, their ventilation systems also differ. For the Lafontaine Tunnel, there are 16 vertical fans and, in 13 years, only one has needed reconditioning. Moreover, none of the 16 fans has suffered significant rust or dirt deterioration, which is undoubtedly due to the fact that the motor and dynamic brake are protected by a self-cooling casing. On the other hand, lack of proper access to the air shafts has caused problems in the handling of spare parts. The installation of doors has partly solved the problem, but it is still difficult to handle parts in eight exhaust fans when breakdowns occur because they are located above the roadways.

Sixty-three fans, which are located in five towers, make up the Ville-Marie Tunnel ventilation system because of the special geometry of the traffic lanes. Handling spare parts is also extremely difficult for 18 of the 63 fans. However, with a little imagination, a solution to part of the problem of lack of access to the fans was found. Instead of using a mechanical winch to make fan repairs, an I-beam with a manually operated trolley was installed, which requires much less maintenance and is cheaper to purchase.

I should also mention that the fan air louvers are often jammed--the victims of rust and dirt--because their opening and closing hardware is not salt-air proof, which is the source of the problem. However, even though the air louvers function automatically and two employees work full time on preventive maintenance, four or five fans are frequently out of order, which is caused by the air louvers. Moreover, since the motors in the Ville-Marie Tunnel are not protected with metallic casings, they are more easily exposed to corrosion, particularly the manually operated brakes. In the long run, it also happens quite often that the propeller blades catch in the ventilator frames. Since 1974, six have had to be replaced. To solve only the air-louver problem would cost approximately $600 000.

Based on experience with the Lafontaine and Ville-Marie Tunnels, suppliers of fans for the Viger Tunnel, which is now under construction, have been given stricter specifications. In the future, the opening and closing hardware for air louvers must be mounted on ball bearings. In addition, all parts of this hardware must be metallized in plant for protection against salt air. As for the ventilator motors and emergency brakes, these must have a metallic casing before being equipped with their own aeration system. In the Viger Tunnel, access to all fans is planned, thereby easing the handling of various spare parts.

Both the Lafontaine and the Ville-Marie Tunnels have a carbon monoxide monitoring system to check the quality of the air. A Hopcalite analyzer was first installed in the Lafontaine Tunnel. However, it required extensive maintenance and proved difficult to calibrate. Furthermore, the pumps used for air sampling, which were placed inside the cubicles, had a tendency to overheat; it was therefore necessary to place them outside the cubicles. Here, too, follow-up service was more or less satisfactory and spare parts were difficult to come by. Therefore, considering the many problems encountered, this carbon monoxide monitoring system was replaced a few years ago with an infrared system similar to the one in use in the Ville-Marie Tunnel. Calibration of this type of analyzer is simpler and readings are more accurate. Furthermore, its maintenance is done by department personnel.

POWER SUPPLY

Hydro-Québec provides the electricity that is essential, needless to say, for the efficient operation of all installations in both tunnels. But for obvious reasons, another source of power had to be available in case of a breakdown in the Hydro-Québec system. This is why a static inverter was installed when the Lafontaine Tunnel was built. This was supposed to supply essential services to the tunnel until the motor generator sets started and absorbed the load. However, the static inverter, which was one of the first of its kind, needed extensive repair work and had one major defect--it broke down at the same time as the Hydro-Québec power failure. It was scrapped in 1969 and never replaced. To compensate for the lack of a static inverter, signs were put up at the entrances to the Lafontaine Tunnel urging motorists to turn on their headlights. According to statistics, 40 percent of the tunnel users do turn them on. The motor generator sets are also turned on during violent storms, ready to take over in case of a power failure. The authorities are now seriously thinking about installing proper inverters to cope with this situation.

The Ville-Marie Tunnel was built at a later date, so it has the advantage of being equipped with a different system for the provision of emergency current. In fact, noninterruption units are installed in each ventilation tower, which provide one-sixth of normal lighting during a power failure and feed the control systems essential for efficient tunnel operation during the lapse of time it takes for the motor generator sets to start functioning, which is approximately 3 min. The noninterruption units are equipped with an AC-DC rectifier, a storage battery, a DC motor, and an alternator. This system has proved most reliable. However, it does require constant maintenance by both the manufacturer and maintenance personnel.

Also, fire broke out in the storage battery room when the noninterruption units were first put into operation. Battery overloading, together with an overflow of acid (rendering the cases current conductors), were the cause of the fire. To solve this problem, hydrocaps had to be fitted to the batteries to condense the acid fumes. Preventive maintenance is done on all batteries; for instance, the water level is checked regularly. The same type of noninterruption units will be installed in the Viger Tunnel.

EMERGENCY EQUIPMENT

In the Ville-Marie Tunnel, there have been many problems with the opening and closing hardware on the doors leading to emergency hallways. Made of conventional steel, these parts were not sturdy enough, got rusty, and jammed easily. They are gradually being replaced with hardware made of stainless steel, like the doors themselves.

Both tunnels are equipped with fire hose cabinets. In the Lafontaine Tunnel, these are large and easy to reach from the emergency hallways, rendering their inspection and maintenance simple enough. On the other hand, the fire-fighting equipment cabinets in the Ville-Marie Tunnel are small, and maintenance personnel have to use a roadway to do the maintenance work, which means closing one traffic lane.

Moreover, fire hoses frequently burned because they were placed too close to heaters. It was decided to roll the hoses instead of suspending them, thereby moving them away from the heaters. And, finally, neoprene-lined hoses, known for their high resistance to cold, were installed in both tunnels.

CONCLUSION

Tunnel designers should bear in mind both tunnel operation and maintenance. In order to minimize the problems and costs related to monitoring and maintenance of future tunnel sections, designers should, and must, consult those in charge of these two essential operations and profit from their past experience. A more judicious choice of lane geometry, materials, and equipment would certainly result from such consultation. The future tunnel section will, therefore, be of optimum design from a structural, mechanical, and functional point of view.

Keeping this objective in mind, the Québec Ministère des Transports has taken into account specific problems encountered in the operation and maintenance of the Ville-Marie and Louis-Hippolyte-Lafontaine Tunnels. The new Ville-Marie expressway tunnel--the Viger Tunnel--will therefore show significant improvements over the other two tunnels.

As a matter of fact, rendering the task of those in charge of operations and maintenance easier should be the main outcome of recommendations made to the consulting engineers working on the tunnel design, while at the same time ensuring greater safety for motorists.

Variable Pitch Axial Flow Fans for Tunnel Ventilation: A Comparison with Centrifugal Fans

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Variable pitch axial flow fans for application in vehicular tunnel ventilating systems are described. The fan design is of German origin and is considered to represent the state of the art, matured over more than two decades of operating experience. Its use for tunnel ventilating systems in the United States appears to be justifiable. The design and performance are described. Three major areas—energy conservation, space requirements, and number of pieces of equipment—provide the largest savings potential and make this fan design most attractive.

The ever-increasing cost of energy is influencing our personal lives as well as our ability to be competitive in a world market. In that regard, the demand for energy conservation has become not only a political factor, but it is also beginning to play a significant role in today's capital-investment decisions, in that operating costs frequently equal or exceed the cost of the initial capital investment. As engineers, therefore, we are obliged to use all available technology or develop new means to reduce or optimize the use of energy to balance and control its impact on the economy.

The purpose of this paper is threefold:

1. To identify major factors that make axial flow fans the best economic choice for capital investment decisions (i.e., reduction in number of operating equipment and reduction in space requirements);
2. To demonstrate that the variable pitch axial flow fans (VPAFFs) used for continuous flow control will significantly reduce total power consumption, which will result in operating cost savings; and
3. To briefly discuss the VPAFF's reliability, noise emission, maintenance, and general vulnerability to tunnel fires.

This paper will not discuss the theory behind fan laws. It will state theory where necessary and use resulting design criteria as required to demonstrate points and make comparisons.

AXIAL FLOW FANS--THE BEST ECONOMIC CHOICE

Reduction in Number of Operating Equipment to Satisfy Ventilation Requirements

A brief explanation of centrifugal and axial fans is given below:

1. Centrifugal fans: A centrifugal fan is a fan whose inlet air enters the fan parallel to the axis of impeller rotation, is turned, and then leaves the fan perpendicular to the axis of rotation. Centrifugal fans are best suited for low-volume flow, high-pressure application. Their use for higher volume flows is accomplished by using the double-width double-inlet (DWDI) design, where two centrifugal fans essentially operate in parallel.
2. Axial fans: An axial fan is a fan where the air enters the fan parallel to the axis of impeller or rotor rotation and leaves the fan with the air still parallel to the axis of impeller rotation. Axial flow fans are best suited for high-volume flow, low-pressure application. Two or more impellers in series are used to extend the axial flow fans use to higher pressure ranges.

Figure 1 shows a simplified method to determine what type of fan or how many fans must be used to meet a given set of conditions. Three variables (volume flow, adiabatic head, and fan speed) characterize the fan's specific speed and indicate the preferred fan type (axial or centrifugal).

To help explain this concept, the following example is given. The total volume flow for a tunnel ventilation section may be 900 000 actual cubic ft/min (ACFM) at 2-in watergauge (w.g.). In selecting DWDI centrifugal fans, it can be recognized that at least three fans, operating at 300 revolutions/min (rpm) or below, should be used to meet volume flow.

When considering axial flow fans, it can be seen that one or two fans operating at 350-600 rpm or above can be used. Considering the example, the following observations can be made:

1. Fewer fans are required to move the ventilation air volume flow when using axial flow fans;
2. The higher operating speed of axial flow fans usually permits the use of directly coupled drive motors;
3. Equivalent to the number of fans, fewer drive motors are required;
4. Less motor starting and auxiliary electrical equipment are required;
5. Fewer dampers and damper drives are needed;
6. Fan or motor controls will be simplified;
7. Fewer foundations are required; and
8. The ductwork requirements will be reduced.

Although not quantified in this paper, the items listed above will reduce the overall equipment costs, particularly installation costs.

Reduction in Space Requirements (Reduction of Fan Building Costs)

The costs of the ventilation fan building represent a substantial portion of the total tunnel costs. To keep the fan building costs at their lowest, it is desirable to minimize its physical size. The size of the building, however, is in most cases primarily affected by the number of fans to be installed and their dimensions. With this in mind, the objectives