FIRE IN THE COINTE TUNNEL : A DESIGN CASE STUDY

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ABSTRACT

Since the COINTE tunnel in Liege, Belgium, had been designed for a semi-transverse ventilation system, the solution commonly adopted with this kind of system in case of fire, is extracting smoke through openings in the roof. The dimensions of these openings, as well as the extracting capacity of the entire fan system are calculated according to some thumb rules, themselves, of course, being determined by the so-called "maximum" heat release rates of a fire that the designers agree on to take into account.

However, besides a sufficient extracting capacity, of equal importance, if not more, is having the smoke movements in the tunnel under control. Experience and simulations show that this control is at best achieved with a longitudinal ventilation system.

Hence, the combination of both ventilation systems would normally cover a wider range of fires. Simulations on computer showed indeed that, if the COINTE tunnel has to allow traffic of dangerous goods, the initial solution would by far not suffice to master high fire loads that can go up to ... 250 ... 300 MW.

The objective of the paper is to discuss this solution, probably unique, that the authors propose for the COINTE tunnel.

Based on information from literature, and own experience, the paper reviews the current state of art. It develops the underlying assumptions where the design in general, and that of the COINTE tunnel in particular, is based on.

INTRODUCTION

COINTE tunnel, brief description

Considering that the important city of Liege has always been a crossing of trade ways, a lot of heavy transit traffic is observed on both the important motorways, the one being the E40 that runs from Liege into the Ardenne and further to Luxembourg, and the other the E25 that links Liege to Brussels and further to the coast side and the harbour of Antwerp.

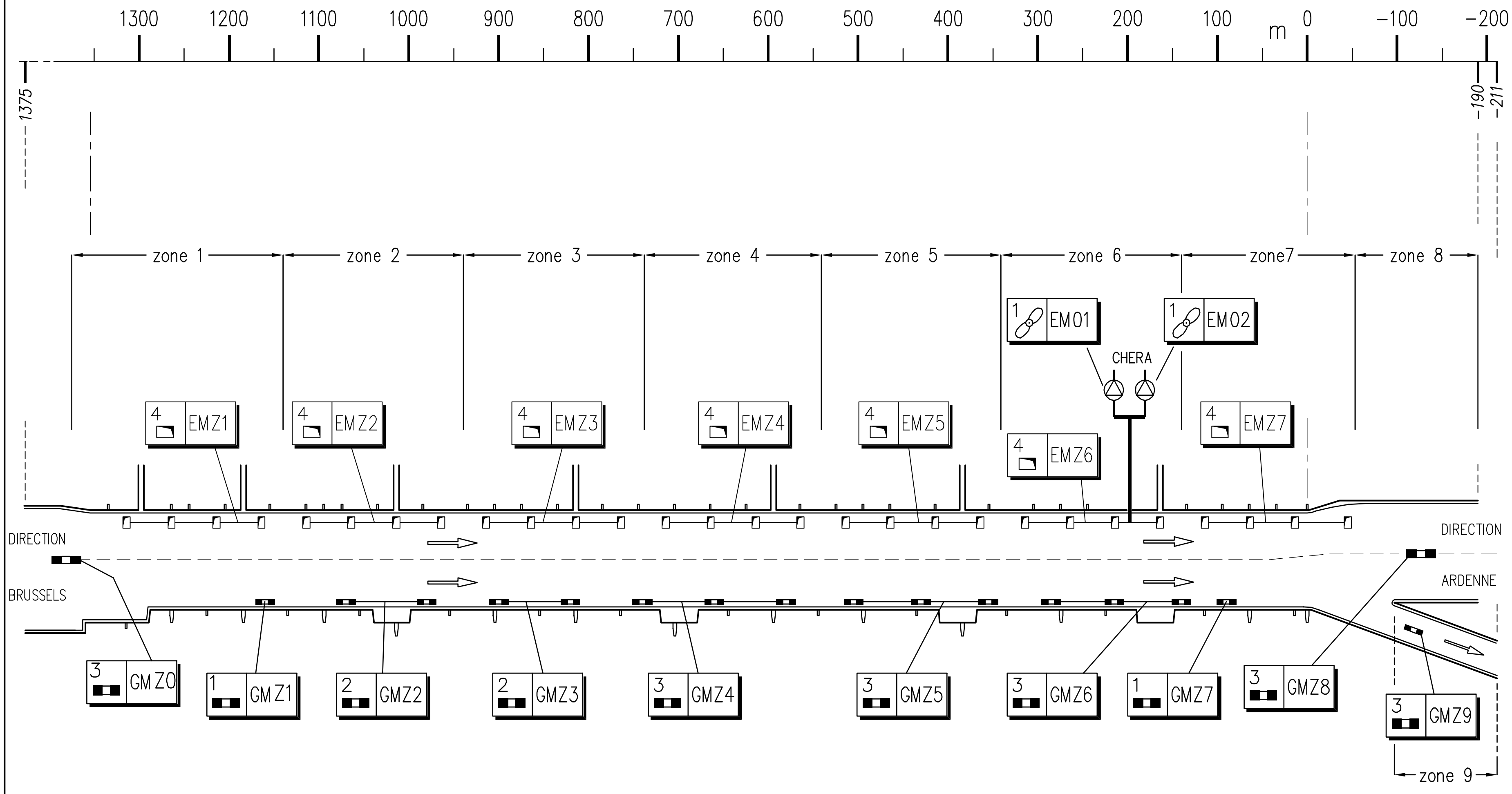

Figure 1. Schematic lay out of the COINTE tunnel "Amont"

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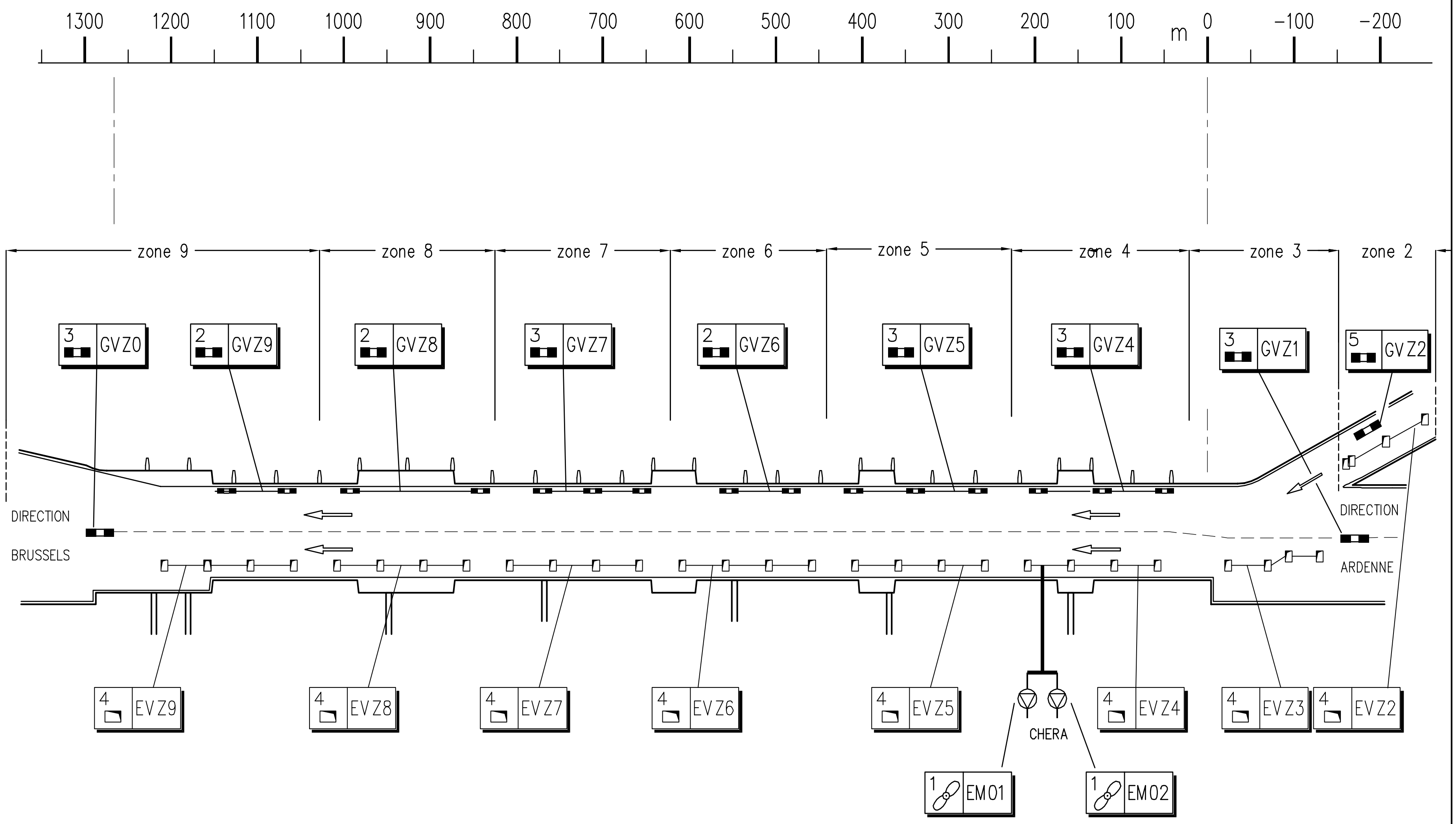

Figure 2. Schematic lay out of the COINTE tunnel "Aval"

For the time being, all the heavy transit traffic is passing through the city, bringing along a lot of nuisance (dangerous goods, congesting traffic, heavy pollution, and so on...). Therefore, it has been decided that the link between these two motorways would be a series of three twin tube tunnels and a bridge built over the Mouse. The most important among them is the COINTE tunnel with a length of approximately 1300 m. Once finished, this tunnel will be made of two one-directional tubes each of them having a dual carriage way.

The main ventilation system is of the semi-transverse type, which means that fresh air is blown into the tunnel all along through openings in the walls. Only the access roads are ventilated by means of jet-fans. In view of protecting the environment, the major part of the polluted air will normally be extracted before reaching the exit portals, and will be evacuated through a chimney located on the top of the COINTE hill.

Since the entire traffic is now supposed to drive through the tunnels, of which at least 10 % is expected to be heavy vehicles, the presence of dangerous and flammable goods inside the tunnel will be a fact. Till now, no official authority decisions have been taken, either to forbid, or at least to regulate the passage of these dangerous goods. Therefore, risk of fire hazards is unfortunately not only not hypothetical, but, if it occurs, the extent of the danger could well be considerable.

Building up quantitative pictures of possible worst case fire scenarios must, therefore, be the first concern when designing the ventilation capacity. In fact, by doing this exercise, it becomes obvious that the ventilation capacity is in the first place determined by the fire hazard criterion.

The up-to-date knowledge gained from experimental full scale tests (Memorial tunnel in Boston, EUREKA project EU 499 FIRETUN), leads us to consider that in the case of the COINTE tunnel important fire loads representing values of 150 ... 200 MW and, in some cases even up to 300 MW, have to be taken into consideration.

OBJECTIVE OF THE PAPER

The objective of the paper is a study of possible fire scenarios that could occur and of the means that must be provided in order to reduce the harmful consequences of smoke development in the tunnel. With background information on fires and smoke generation available in literature, the paper aims primarily at :

- discussing the ventilation strategy that needs to be achieved,
- defining fire scenarios that could occur,
- modelling the ventilation for different heat production rates of the fire in view of maximum smoke extraction and preventing back-layering to occur,
- specifying size and characteristics of the mechanical equipment, and,
- proposing the most adequate means for operating and controlling it in order to reduce efficiently the harmful consequences of a fire.

PROBLEM CONTEXT

Fire and smoke spread

When a fire occurs and develops in a tunnel, it has usually consequences that are a lot more severe than an equivalent fire in the open air. Aggravating factors are e.g. confined space, limited number of escape roads, flashing over, loss of visibility, etc.
From the user's point of view, the two major enemies are toxicity of smoke and heat release of the fire.

An understanding of what is likely to happen in the event of a fire is essential for the formulation of the adequate measures to be taken in order to counter its consequences. The study of an hypothetical fire must take into account mainly two factors :

- hot smoke stays stratified in an upper layer for hundreds of meters from the fire location if the longitudinal air velocity in the tunnel remains low. It is only after the smoke being cooled down by heat exchange with surrounding walls and the fresh air layer underneath that the entire cross-section of the tunnel starts to fill up with smoke;
- from the traffic point of view, the location of a fire in a one-directional tunnel will naturely divide it into two parts : a part downstream of the fire where the traffic should be able to leave the dangerous area and reach the exit portal as soon as possible, and the upstream part where traffic is hold up by the developing fire.

Therefore, efficiency from the ventilation point of view would mean that two purposes are served simultaneously :

- extract as much as possible smoke while it travels along the roof or the ceiling without disturbing as less as possible the natural layering of hot smoke, and,
- keep an area free from smoke. In an one-directional tunnel this area is, of course, the one upstream of the fire. In a bi-directional tunnel the underlying idea would rather be confining the smoke in an area as small as possible.

The first demand would need an efficient extracting system with exhaust openings in the roof, a collecting duct and fans capable of operating at high temperatures.

The second one would need a sufficient piston force to avoid smoke from back-layering. Indeed, back-layering can be countered by keeping up a minimum air velocity upstream of the fire.

Ventilation systems

Transverse systems with a fully developed extracting system are usually suitable, at least for small fires with a limited smoke quantity produced, since this ventilation system is provided with exhaust openings designed for the polluted air to be extracted. Boosting this system to a higher extracting capacity and higher thermal resistance would only be a matter of choosing the right equipment.

On the contrary, semi-transverse systems initially do not, by definition, have exhaust systems. Therefore, the ample space on the top of the cross-section, at least with excavated tunnel types, could be used to extract the smoke provided that openings in the ceiling are designed.

Longitudinal systems on the other hand allow to fulfil the second demand as long as the ventilation capacity is sufficient, but ultimately the tunnel will fill with smoke so hindering the fire brigade and the rescue people to near the fire from the downstream side.

Thus, the idea is obvious : let us take advantage of both the semi-transverse and longitudinal ventilation system by combining them.

COINTE tunnel ventilation system

In the particular stringent case of the COINTE tunnel where severe fire hazards could occur, a first series of calculations that takes into consideration only the extracting capacity of the fans through the designed openings in the roof, made it clear that severe problems would arise if a fire indeed released heat rates of over 30 MW. Although this kind of calculations needs a lot of assumptions to be made, among others on the sort of materials or goods that will burn and how it will burn, on what the volumes of released smoke and their temperature could be, and so on, it was right away obvious with some figures of CETU at hand, that large fires could not be handled.

On the other hand, a second series of calculations showed that if the ventilation were restricted to a single longitudinal system (by closing the openings in the roof) it wouldn't be sufficient either to manage these important fire loads. The aeraulic resistance of the downstream part would increase significantly while the volume flow, due to the temperature rise, would also be significantly increasing. In these severe cases, the total thrust developed by all the jet-fans would not be sufficient to overcome the pressure losses.

But, by extracting part of the smoke quantity (with inevitably a certain fraction of fresh air), two parallel paths are created with the obvious result that both the volume flow rates in the downstream part of the tunnel and its aeraulic resistance value are reduced.

This concurrent effect explains why a solution that combines a semi-transverse with a longitudinal ventilation system, at least in its design stage, promises attractive features for the COINTE tunnel.

Finally, the study ends up with a proposal for a double ventilation system (see figures 1 and 2) :

- Exhaust system

  The initial project provided the tunnel with openings all along the roof, at every 50 m. These openings, grouped by four and referred to as EMZ1 ...7 in figure 1, and EVZ2 ...9 in figure 2, have a cross-section of approximately 3 m^2, and when opened, they put the tunnel in connection with a collecting duct having a cross-section of 12 m^2. At the end of this duct two fans in parallel enable a total extracting capacity of up to 200 m^3/s. The traps, normally in closed position, are operated on a signal emitted by the control system. No decision has been taken yet on the mechanism that will be used for operating these traps.
- Jet-fan system

  For each tube, 30 jet-fans of the classical type. i.e. with an inner diameter of 0.56 m and a jet velocity of 35 m/s, have been projected. They are referred to by GMZ0 ... 9 in figure 1, and GVZ0 ... 9 in figure 2. For mere practical reasons related to problems of location and necessity to find sufficient distance along the tunnel between the jet-fans, a few sets of smaller ones have been replaced by bigger jet-fans : they are 6 with an inner diameter of 1 m.

Fire scenarios

There is no authority in Belgium that states about the maximum heat release rates that must be taken into account for designing the ventilation capacity of a tunnel. Neither are there real international agreements on this point. Some guide figures are given by PIARC [1].

However, there is a common tendency to reconsider these values. Indeed, unfortunate fire cases on the one hand (e.g. in the Channel tunnel) and, organised experiments [2] and simulation [3] on the other hand, tend to convince that future design criteria where traffic of dangerous goods are concerned, must move upwards to limit values of around ... 200 ... 300 MW.

For instance, the new KIVI [4] design criteria in the Netherlands take into consideration heat release rates of 300 MW, in France the CETU [5] claims now values of 200 MW if a petrol tanker is involved.

This study does not concern the chemical and physical aspects of the fire, only considers fires as a source of heat and smoke production rates at certain locations in the tunnel. Taking the layout of each tube of the tunnel and the location of the exhaust openings into consideration, it is easy to observe that, from the ventilation point of view, all possible fire situations along the tunnel could be reduced to ten different scenarios. Once these scenarios identified, they enable us to subdivide the tunnel, or more precisely each tube, into ten operational zones.

This approach has two main advantages :

1. From the design point of view, the complexity and the number of simulations could be maintained within reasonable limits. For each fire scenario, three heat release rates were simulated, each of them being examined with and without wind influence. All these combinations needed to be carried out for both the tubes, which nevertheless brings the number of simulations to 120.

2. From the operational point of view, the control system can start up, without delay, one of these predefined procedures, once the fire has been properly located. This advantage is particularly precious, since the complexity of the ventilation system is such that it would be asking too much of an operator to schedule in so short a time all the necessary and appropriate actions such as opening the involved exhaust traps, starting up some of the fans and in the right sequence, switching off others, and so on. This is all the more true that fire situations are (hopefully) not frequent, and therefore the operator lacks practical training.

CALCULATION METHODOLOGY

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Simulation of fire

As explained, the COINTE tunnel has been divided into a certain number of zones, the modelling of each of them being based on the same calculation principles. Figure 3 shows the aeraulic equivalent scheme in case of fire in zone *i.*

The underlying assumptions are :

- For each zone the corresponding subset of equipment being put in operation, it is supposed that the traps at the eight exhaust points in zones *i* and *i+1* are open.
- The twin fans having a total flow rate capacity of 200 m^3/s, the extraction is supposed to be equally distributed over these eight openings.
- Since it can not be avoided that fresh air is also extracted, it is furthermore supposed that 50 m^3/s of fresh air is extracted at the first two openings, and 150 m^3/s of smoke through the last six openings.
- The jet-fans located outside zones *i* and *i+1* are in operation. On the other hand, the jet-fans located in the zones *i* and *i+1* are supposed to be out of order and thus stopped.

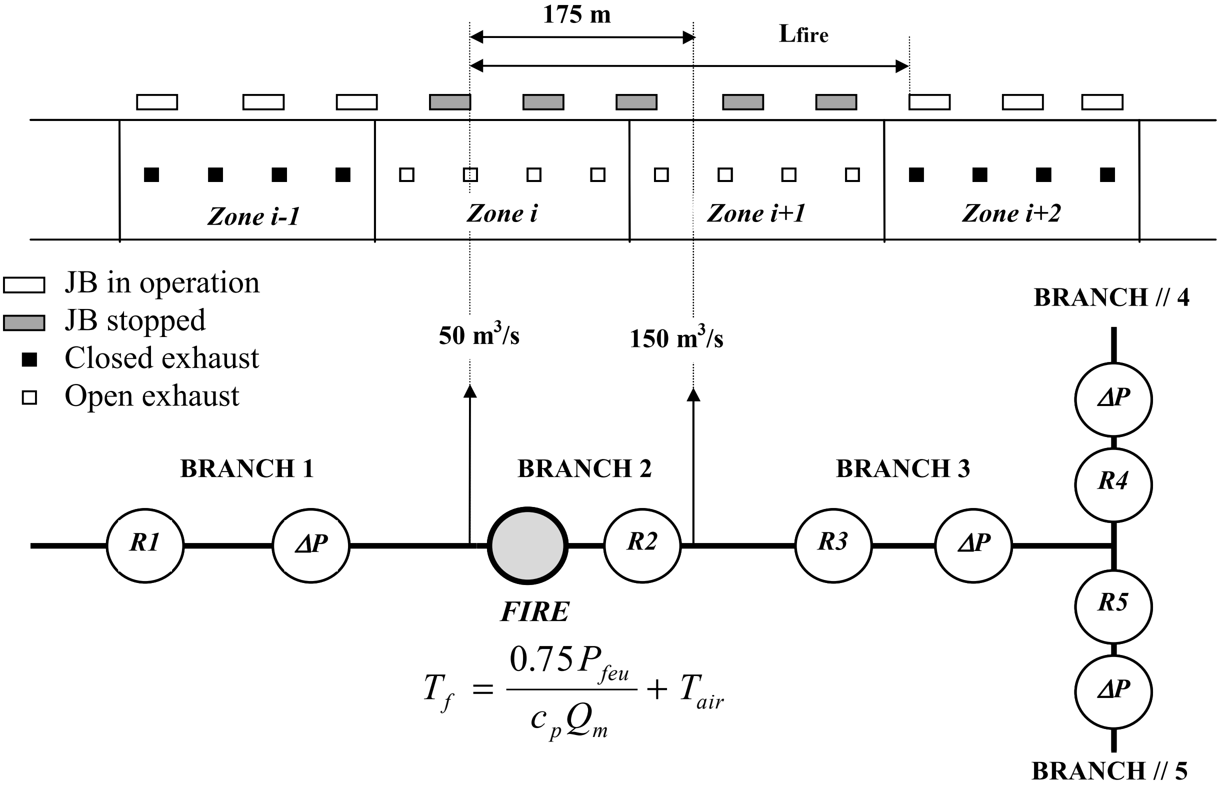

Figure 3 : Simulation of fire

Calculation of a branch characteristic

The general equation of a flow between an input node E and an output node S is written as follows :

$$\Delta p_{S-E} = \sum_{i}^{n} \Delta p_{JF,i} - \Delta p_{f,E-S} - \Delta p_{p,E-S} - \Delta p_{w} \ ,$$

with $\Delta p_{S\text{-}E}$ is the pressure difference between S and E,

$\Delta p_{JF,i}$ the driving pressure of a jet-fan,

$\Delta p_{f,E\text{-}S}$ the friction pressure loss,

$\Delta p_{p,E\text{-}S}$ the pressure variation due to the piston effect of vehicles,

Δp_{w} the counter pressure due to the wind, and,

n the number of jet-fans.

Driving pressure of a jet-fan

$$\Delta p_{JF,i} = \rho k v_t^2 \frac{\Omega(1-\theta)}{\theta^2} \ ,$$

where

k is the efficiency coefficient of a jet-fan,

ρ the air density,

v_t the upstream mean velocity in the tunnel,

Ω the ratio between the JB fan cross-section and the tunnel cross-section, and,

θ the ratio between the upstream mean velocity and exhaust velocity of the fan.

Friction pressure loss

$$\Delta p_{f,E-S} = \left(\xi_E + \xi_S + \lambda \frac{L}{D_h} \right) \frac{Q_m ABS(Q_m)}{\rho S_t^2} \ ,$$

where

ξ_E is a singular pressure loss coefficient at the entrance,

ξ_S a singular pressure loss coefficient at the outlet,

λ the Moody coefficient,

S_t the cross-section of the tunnel,

L the branch length,

D_h the hydraulic diameter,

Q_m the volume flow rate, and,

ABS a mathematical operator for taking the absolute value.

Piston effect of vehicles

$$\Delta p_P = \frac{\rho}{2} \frac{(v_{JF} - v_t)|v_{JF} - v_t|}{A} (N_C C_{x,C} A_C + N_H C_{x,H} A_H) n_L L \ ,$$

where

$C_{x,C}$ and $C_{x,H}$ are the average drag coefficients of cars, respectively trucks,

A_C and A_H the average resistance areas of cars, respectively trucks,

N_C and N_H the number of cars, respectively trucks per km,

n_L the number of lanes,

L the length of the considered tunnel section in km,

v_{JF} the jet velocity of the jet-fan in m/s, and,

v_t the average air velocity in the tunnel in m/s.

Counter-pressure due to the wind

$$\Delta p_w = \rho \frac{v_w^2}{2}$$

where v_w is the average wind velocity in m/s along the axis of the tunnel.

Evaluation of smoke temperature

A good estimation of the smoke temperature is important because it determines the density of the gas downstream the fire which strongly influences each term of the branch characteristic.

The smoke produced by the fire is cooled down during its travel along the colder walls of the tunnel. However, the walls which at the start of the fire are at ambient temperature, gradually warm up by the smoke during the considered time period. As a consequence, the heat transfer between smoke and walls is reduced so the temperature of the smoke is increasing. Obviously, the temperature of the smoke at a certain location depends not only on the distance from the fire but also on the time after the beginning of the fire.

This evolution can be seen in three steps :

1. Evolution of the smoke temperature as a function of the distance from the fire at the time the fire starts, for an initial wall temperature, let it be 20 °C.
2. Calculation of the average temperature rise of the walls after e.g. 15 and 30 minutes, considering a constant temperature of the smoke equal to the mean temperature obtained at the beginning of the fire.
3. Determination of the smoke temperature as a function of the distance from the fire for the wall temperature evaluated at step 2.

Temperature versus distance from the fire

The energy balance applied on a length *dx* of the tunnel can be expressed as follows [6] :

$$Q_m c_p \frac{dT_f}{dx} = Pdx\, h_f \left(T_f - T_p\right) + Pdx\, \sigma\, \varepsilon \left(T_f^4 - T_p^4\right)$$

In this relation,

Q_m is the mass flow rate of smoke in kg/s,
c_p the heat capacity of smoke in J/kg/K,
T_f the smoke temperature in K,
P the tunnel perimeter in m,
h_f the convection heat transfer coefficient in W/m^2/K,
T_p the wall temperature in K,
σ the constant of the Stefan law equal to 5.415 10^{-8} W/m^2/K^4, and,
ε the emissivity coefficient of tunnel walls (0.95).

The second term of the equation represents the radiation heat transfer which becomes important at high smoke temperature (near the fire).

The convection heat transfer coefficient is taken from the following correlation :

$$Nu = 0.0183\left(\mathrm{Re}^{0.8} - 100\right)$$

with

$$Nu = \frac{D_h \cdot h_f}{\lambda_f}$$

$$\mathrm{Re} = \frac{v \cdot D_h \cdot \rho_f}{\eta_f}$$

where

Nu is the Nusselt number,
Re the Reynolds number,
D_h the hydraulic diameter of the tunnel in m,
λ_f the thermal conductivity of smoke in W/m/K,
v the average velocity in m/s,
ρ_f the smoke density in kg/m^3, and,
η_f the smoke viscosity in Ns/m^2.

The smoke properties are supposed to be similar to the ones of air.

The energy balance equation is numerically integrated starting from initial conditions determined by the fire load.

Temperature versus time

The temperature evolution during time is based on the following assumptions :

- The smoke temperature is supposed to be constant and equal to the mean spatial temperature over the distance L from the fire at time t=0.
- The convection heat transfer coefficient is supposed to be constant and is determined at time t=0.
- The wall thickness is considered as being a semi-infinite solid medium. The results will confirm this assumption.

This well defined problem corresponds to the transient heat transfer problem throughout a solid medium submitted to a fluid at constant temperature. The solution of this problem is well known and is given as a function of two non-dimensional parameters :

- parameter ξ $$\xi = \frac{x}{2\sqrt{\alpha t}}$$

- parameter ψ $$\psi = \frac{h\sqrt{\alpha t}}{k}$$

In these relations,

x is the distance inside the semi-infinite solid,
α the thermal diffusivity of the solid,
t the time,
h the convection heat transfer coefficient between the fluid and the wall, and,
k the thermal conductivity of the solid.

The thermal properties of the solid are given in the following table.

Density (kg/m^3)	*2400.00*
heat capacity (J/kg/K)	*840.00*
conductivity (W/m/K)	*1.75*
thermal diffusivity (m^2/s)	*8.681 E-07*

The results are shown in the next table where *ΔT* is the temperature difference between the fluid and the wall.

Time (min)	***Parameter*** ψ	$\dfrac{\Delta T(x=0,t)}{\Delta T(x=0,t=0)}$	***Penetration depth in solid (mm)***
15	0.48	0.62	82
30	0.68	0.54	107

These values are used for determining the average temperature of the wall after 15 and 30 minutes.

RESULTS

All the simulation results are brought together in the table 1 for the "Amont" tube of the tunnel.

FIRE CASES

COINTE tunnel "Amont"

REF.	***ZONE***	***Upstream Velocity (m/s)***			***150 MW - Temperature Tunnel (°C)***				***150 MW - Temperature Extraction (°C)***			
		50 MW	***100 MW***	***150 MW***	***Tf at 0 m***	***T(0 min)***	***T(15 min)***	***T(30 min)***	***Tf at 0 m***	***T(0 min)***	***T(15 min)***	***T(30 min)***
INC.CM.Z01-VC	Zone 1	*5.761*	*4.279*	*3.043*	*963.00*	*81.78*	*215.50*	*253.02*	*412.00*	*153.16*	*197.51*	*208.42*
INC.CM.Z02-VC	Zone 2	*4.696*	*3.618*	*2.788*	*1098.98*	*81.33*	*239.11*	*283.06*	*441.44*	*155.42*	*202.61*	*214.36*
INC.CM.Z03-VC	Zone 3	*4.076*	*3.351*	*2.825*	*1076.59*	*74.23*	*232.98*	*276.08*	*436.84*	*155.11*	*201.86*	*213.48*
INC.CM.Z04-VC	Zone 4	*3.670*	*3.189*	*2.847*	*1063.84*	*70.74*	*229.67*	*272.27*	*434.18*	*154.93*	*201.42*	*212.96*
INC.CM.Z05-VC	Zone 5	*3.511*	*3.212*	*3.001*	*982.92*	*77.80*	*217.51*	*256.16*	*416.55*	*153.56*	*198.34*	*209.38*
INC.CM.Z06-VC	Zone 6	*3.513*	*3.301*	*3.157*	*912.51*	*105.16*	*217.33*	*250.92*	*400.09*	*152.03*	*195.22*	*205.80*
INC.CM.Z07-VC	Zone 7	*3.230*	*3.171*	*3.099*	*635.40*	*177.84*	*234.32*	*251.04*	-	-	-	-
INC.CM.Z08-VC	Zone 8	*4.115*	*3.580*	*3.094*	*636.32*	-	-	-	-	-	-	-
INC.CM.Z09-VC	Zone 9	*5.295*	*4.391*	*3.671*	*747.30*	-	-	-	-	-	-	-
INC.CM.Z01-SV	Zone 1	*6.740*	*5.516*	*4.544*	*561.24*	*126.56*	*185.13*	*201.53*	*297.74*	*136.15*	*169.04*	*176.77*
INC.CM.Z02-SV	Zone 2	*5.565*	*4.678*	*4.014*	*657.06*	*126.99*	*196.06*	*216.23*	*329.59*	*142.39*	*178.59*	*187.20*
INC.CM.Z03-SV	Zone 3	*4.839*	*4.227*	*3.785*	*709.70*	*107.49*	*189.63*	*213.34*	*345.70*	*145.07*	*182.90*	*191.96*
INC.CM.Z04-SV	Zone 4	*4.341*	*3.927*	*3.636*	*749.20*	*98.75*	*189.84*	*215.97*	*357.20*	*146.80*	*185.78*	*195.17*
INC.CM.Z05-SV	Zone 5	*4.086*	*3.825*	*3.645*	*746.58*	*100.38*	*190.41*	*216.30*	*356.46*	*146.70*	*185.60*	*194.96*
INC.CM.Z06-SV	Zone 6	*4.008*	*3.823*	*3.704*	*730.62*	*102.21*	*189.25*	*214.27*	*351.85*	*146.02*	*184.46*	*193.70*
INC.CM.Z07-SV	Zone 7	*3.715*	*3.659*	*3.585*	*551.92*	*185.54*	*233.35*	*247.01*	-	-	-	-
INC.CM.Z08-SV	Zone 8	*4.274*	*3.682*	*3.154*	*624.69*	-	-	-	-	-	-	-
INC.CM.Z09-SV	Zone 9	*5.397*	*4.454*	*3.730*	*735.76*	-	-	-	-	-	-	-

Table 1

These results are illustrated in the diagrams below.

Upstream velocity and critical velocity

The air velocity upstream from the fire is given in figure 4, as well as the critical velocity for a fire of 150 MW. This critical velocity has been evaluated by a correlation obtained from the Memorial tunnel tests.

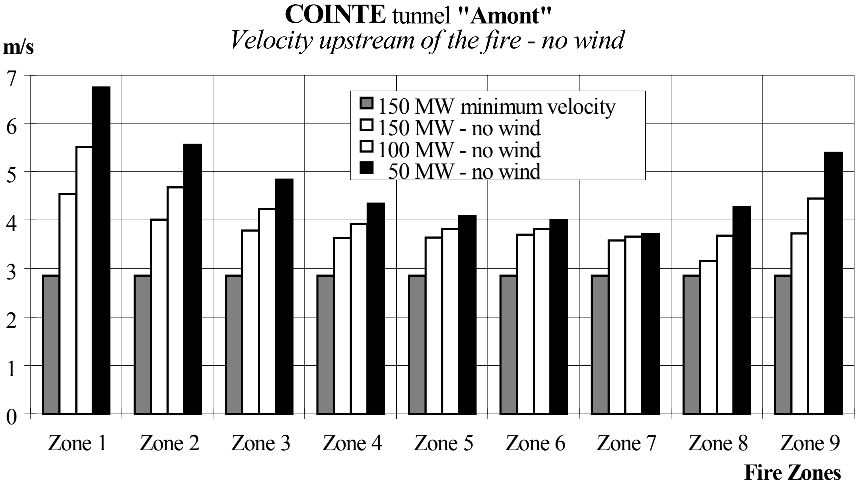

Figure 4.

Smoke temperature

The smoke temperature are reported in figure 5. The following temperatures are given :

- Initial smoke temperature (fire temperature).
- Smoke temperature at the first downstream jet-fan in operation for three time values (at the beginning of fire, after 15 and 30 minutes).

We may observe that the temperature has very high values for fires of 150 MW and more.

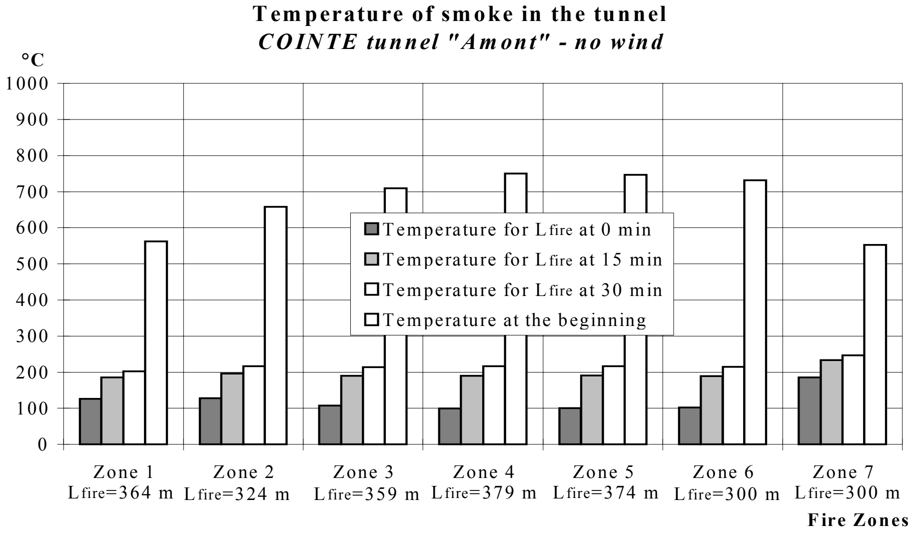

Figure 5.

<u>Smoke temperature versus time</u>

The temperature profile corresponding to three time values is displayed in figure 6 for the fire case referred to as INC.CM.Z01.VC.

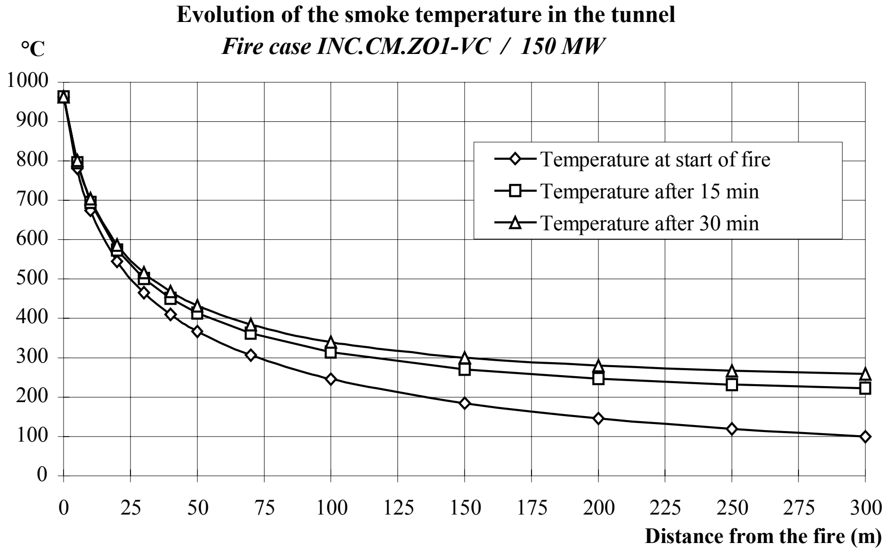

Figure 6.

We may observe that the temperature drops rapidly with the distance from the fire. This shows clearly the benefit of extracting the smoke as near as possible to the fire.

DISCUSSION and CONCLUSIONS

Choice of maximum heat production rate

Fires can be very important if transportation of dangerous goods is unconditionally allowed through the tunnel (tankers with fuel or LGP for example), but fortunately, statistics show that their occurrence is low. It is thus in the first place a matter for the authorities to decide whether they invest in an expensive ventilation infrastructure that may stand a very good chance of never being used, or whether they are willing to take greater risks by a lesser ventilation capacity.

So many factors, part of them being not technical, show up when dealing with this problem. Therefore, it has not been the goal of this study to carry out any risk analysis or to decide on the choice of an upper limit value of the maximum heat release rate.

The work merely means to approach this extremely difficult problem by proposing a workable and reasonable solution for the ventilation system of the COINTE tunnel. This solution must make it possible to ensure a higher level of safety in case of more important fires, theoretically and under the assumptions put forward, up to 150 MW.

No thought in this work has been given to what the impact of high temperatures in the immediate vicinity of the fire might be on the mechanical resistance of concrete structures and linings.

Air velocity upstream the fire

In order to prevent back-layering of smoke from occurring, the air velocities at the upstream side of the fire must have a minimum value. The extensive Memorial tunnel tests showed that a value of around 3 m/s suffices. Therefore, the calculations and dimensioning of the equipment has been carried with this value in mind. So, at full capacity, the ventilation of the COINTE tunnel should be capable of maintaining a smoke free zone at the upstream side of the fire, i.e. the section of the tunnel where vehicles are held up by the blaze.

Thermal resistance of the ventilation equipment

Fires generate very high temperatures in a more or less extended vicinity, depending, of course, on their importance. In this zone, there is no doubt that jet-fans and other equipment will not survive. But the remaining equipment must be all the more reliable. It concerns in the first place the extracting fans and in the second place the more distant jet-fans.

The calculations, of which one must be aware that they give only a rough estimation, show temperatures at the input of the extracting fans that are not too far from 250 °C. It would, therefore, be risky to use an equipment that is not capable of resisting for a longer time at at least this temperature.

Where important fires are concerned, some countries (Switzerland, Netherlands, ...) recommend equipment capable of resisting at 400 °C, for a time period of 1h30. Although these requirements may seem too severe, especially what the duration is concerned, it certainly guaranties a higher reliability, which is the most important characteristic that an equipment must have in this situation.

Natural development of a fire versus operating the ventilation equipment

The results of the study and other experimental data show clearly that the propagation of the smoke can be very fast in case of important fire loads (290 m after 1 minute for a fire of 150 MW). This aspect is also discussed in the report about the tests carried out in the Memorial tunnel.

Crucial, therefore, is starting up or boosting the ventilation as fast as possible. Once recognised as a true alarm, the following conditions must be fulfilled :

- the detection must give a correct information concerning the location of the hazard,
- the traps within the hazard zone and those concerned by it, should be opened without delay,
- the extracting fans must be set at their maximum capacity (ignoring their own possible alarms) and these jet-fans must be started up that are programmed to be in operation.

However, this scheme does not mention any considerations about how to schedule the operations in time. Of course, intervention must go on without delay, but, in view of maintaining during the first minutes the natural stratification of the hot smoke layer, it may be a wrong decision to blow into it too rapidly, thus mixing up smoke and fresh air with the inevitable result that the entire cross-section soon will fill up with smoke. The problem of delay is all the more delicate that it depends on the importance of the fire, which is the great unknown. This point is currently under discussion.

Another underlying point for this discussion is that the sequence of the operations is supposed to be run automatically by an expert system. Of course, this automatic procedure stays under control of the operator and can be interrupted at any time. Indeed, it may be possible that the expert system is fooled by a wrong alarm, either a false one or one that indicates a wrong location, which then would run a wrong fire scenario. In this case, the operator must be in the position to stop the procedure and start up a new one that corresponds to the reality he is observing.

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