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Influence of the slope in the ventilation semi-transversal system of an urban tunnel

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Abstract

The covering of a section of the Inner Belt roadway (“*Ronda del Mig*”) in Barcelona gives rise to an urban tunnel of great length (1535 m). The tunnel is divided into two independent parallel galleries and its orientation is North–South, with a 2% upward slope towards the North. Although normal ventilation is achieved with jet fans, between the two galleries there is an interior passage for smoke extraction, in case of fire, through exhaust openings on both sides of this passage. Therefore, the tunnel has a semi-transversal ventilation system for fire incidents.

The behavior of the smoke generated during those possible fire incidents in the traffic galleries was simulated with a commercial code, FLUENT®, which allows a three-dimensional multispecies Navier–Stokes unsteady simulation. The mesh of each tunnel was made with about 250,000 triangular base prismatic cells. The simulated fire had a thermal power of 30 MW and the time step was set to one second, while the simulation covered 15 min.

Special emphasis was put on the influence of the tunnel slope on the smoke’s behavior in each gallery. Simulation results showed that the fans’ capacity established in the project specifications was not enough to extract the smoke of a fire with the simulated power. A significant percentage of the smoke was aspirated through the exhaust openings but the rest continued rising to the tunnel portal due to the slope. This created a great risk mainly in the descending gallery with opposite traffic direction. For a more efficient extraction it was determined that the exhaust sections should be opened upward of the fire’s location. The standard opening, at both sides of the fire, reduced the capacity to extract smoke due to clean air aspiration from the lower portal.

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1. Introduction

The covering of a section of the Inner Belt roadway (“*Ronda del Mig*”) in Barcelona gives rise to an urban tunnel of great length (1535 m). Its layout is almost completely rectilinear, the tunnel orientation is North–South and there is a 2% of upward slope towards the North.

The tunnel has two independent one-way galleries, with two lanes except in the exits, connections, and in a portion of the South end. In what follows, the South–North gallery will be called the “ascending gallery” whereas the North–South gallery will be called the “descending gallery”. The ascending gallery has two access roads for vehicles, and one exit, while the descending one has one access road and two exits. Fig. 1 shows a sketch of the tunnel indicating the relative positions of the access roads and the exits in each gallery.

Both galleries have a rectangular cross section. Their width is 12 m, with heights varying between 4.6 and 6 m. These dimensions determine the location of the jet fans used to ventilate the tunnel in ordinary conditions,

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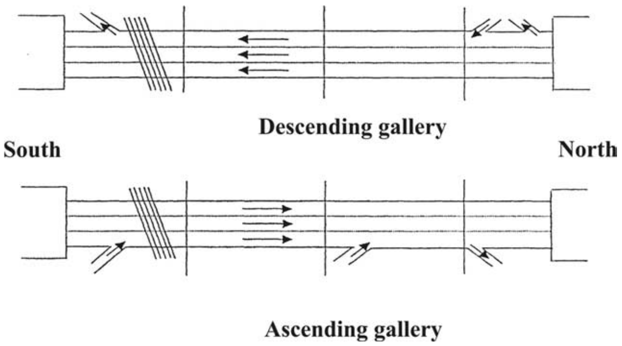

Fig. 1. Layout of tunnel.

which are installed in hollows bays in the central walls of each gallery. Between the two galleries there is an interior gallery, shown in Fig. 2, for smoke extraction in case of fire. It has a variable width from 1.8 to 2.2 m. This compartment has exhaust openings at both sides that can be regulated to extract the smoke at specific places.

This interior gallery is divided into two sections through a thin transverse wall. Two axial flow fans make the extraction in each of the two sectors corresponding to the tunnel length. Therefore, depending on the location of the fire, the closest fan (designed for a 60 m^3/s flow rate) will be activated. In order to optimize the smoke extraction, a second partition was made, consisting of the motorization of the exhaust openings of that gallery in groups of four openings. In this way, and in order to avoid unnecessary air entrance, only the openings closest to the fire location are opened. Thus, the tunnel has a longitudinal ventilation system for ordinary conditions and a semi-transversal ventilation system for fire incidents.

In theory, the design of this installation implies a high level of security. It controls the longitudinal extension of the zone occupied by smoke, in order to minimize the number of potential victims. The effectiveness of the system will depend on its sizing and of its adequate operational procedures. The main risk of the semi-transversal ventilation system is the possibility of excessive longitudinal propagation of smoke, which can occur as a result of pressure differences between the tunnel portals or by the upward effect of the hot smoke combined with the slope (PIARC, 1999; Ministéres de l'Intérieur et de l'Equipement des Transports et du Logement, 2000). In these conditions, the fan might aspirate a high percentage of clean air instead of smoke, requiring oversizing of the facility.

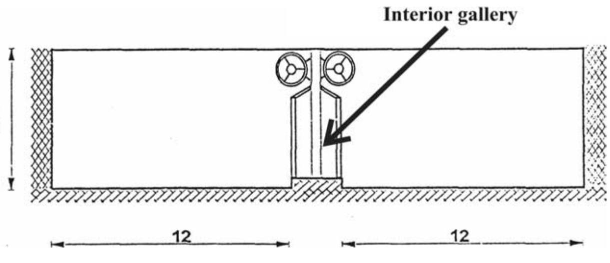

Fig. 2. Cross section of the tunnel (dimensions in meters).

The main goal of this work was the evaluation of the influence of the slope on the smoke displacement along the traffic galleries of the tunnel during possible fire incidents. These studies may define the required extraction capacity and the operation of the exhaust openings in function of the fire location. The existing criteria on smoke control (EUREKA, 1995; Massachussets Highway Department and Federal Highway Administration, 1995) and urban development limitations were also taken into account.

2. Methodology

The study of the smoke propagation during possible fire incidents was carried out with a numerical model, by means of the resolution of the differential equations of conservation of mass, momentum and energy, complemented by turbulent flow models.

Calculations were performed with a commercial software package, FLUENT®. This code uses the finite volume method and solves the three-dimensional Navier–Stokes equations on an unstructured grid. Turbulence was simulated with the standard κ–ε model. Gravitational body force was included in the momentum equations. The buoyancy force due to temperature variations was taken into account through the Boussinesq approximation. The time dependent term scheme was second order, implicit. The pressure–velocity coupling was calculated through the SIMPLEC algorithm. Second order, upwind discretization was used for convection terms and a central difference scheme was used for diffusion terms.

The code was run in a cluster of 8 Pentium 4 (2.4 GHz) nodes. The time step used in the unsteady calculation has been set to 1 s and the number of iterations was adjusted to reduce the residual below an acceptable value in each time step. In particular, the ratio between the sum of the residuals and the sum of the fluxes for a given variable in all the cells was reduced to the value of 10^{-5}.

Since the phenomenon is unsteady, the time dependent terms in the equations were considered and a solution was obtained for any given time step. The solutions consisted basically of three-dimensional fields of the flow variables: velocity (magnitude and direction), static pressure, temperature, species concentration (air and CO_2), density and turbulent magnitudes.

The procedure began with the geometric definition of the numerical domain, that is, each of the tunnel galleries, in all its longitudinal extension, and some zones at

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