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Thermal Radiation Modelling in Tunnel Fires

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Abstract. Modelling based on Computational Fluid Dynamics (CFD) is by now effectively used in fire research and hazard analysis. Depending on the scenario, radiative heat transfer can play a very important role in enclosure combustion events such as tunnel fires. In this work, the importance of radiation and the effect of the use of different approaches to account for it were assessed. Firstly, small-scale tunnel fire simulations were performed and the results compared with experimental data, then realistic full-scale scenarios were simulated. The results show up the capability of CFD modelling to reproduce with good approximation tunnel fires. Radiation proved to be noteworthy mainly when the scale of the fire is relatively large. Among the various approaches employed to simulate radiation, the use of the Discrete Transfer model gave the most accurate results, mainly when the absorption-emission characteristics of the combustion products were taken into account. Finally, the suitability of the use of CFD in quantitative Fire Hazard Analysis is discussed.

AMS subject classifications: 68U20

Key words: CFD, radiation modelling, fire hazard analysis, tunnel fires.

1 Introduction

Quantitative fire hazard analysis is becoming the fundamental tool of modern fire safety engineering practice, and it can help to evaluate and reduce the fire risk in industrial, civil or transport (i.e., road and rail tunnels) enclosures. Fire accidents in road tunnels have recently proven to be extremely costly in terms of human lives, but also in increased congestion, pollution and repairs [1]. The serious threat for lives mainly derives from high temperatures, toxic species, obscuration by smoke and, rad-

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iative heat flux. On the other hand, tunnel closure consequent to fires is prejudicial to national and international economy because it increases transport costs, reduces competitiveness and negatively impacts road safety. The goal of a Fire Hazard Analysis (FHA) is to determine the expected outcome of a specific set of conditions called fire scenario, either in order to find out the hazards that are present in an existing or planned tunnel, or for design and evaluation of the effectiveness of trial fire protection strategies. A tunnel fire scenario includes any details that have an effect on the outcome of interest. This outcome determination can be made by expert judgment, by probabilistic methods using data from past incidents, or by deterministic means such as fire models. The last include empirical correlations, computer programs, full-scale and reduced-scale models, and other physical models [2]. Although empirical correlations and simplified computer models allow a rapid assessment of a fire scenario, because quickly yield a value of the variables of interest, they are heavily limited by experimental conditions and simplifying assumptions [2,3].

In this context, the use of Computational Fluid Dynamics (CFD) techniques may represent an effective way to account for case and site specific details. These codes use a discretisation method in order to approximate the differential flow equations by a system of algebraic equations and solve the simplified balance equations for the conservation of mass, momentum, energy and gas species within the physical domain of interest, thus allowing the estimation of the transient flow patterns of the fire-induced air velocity, temperature, pollutants and smoke concentration in large and complex enclosures. A detailed insight into CFD methodology can be widely found in the literature, e.g., by Shaw [4], Lea [5], Gobeau et al. [3]. In the case of tunnels, CFD modelling for FHA can efficiently be used to evaluate the effects of changes in structural design and ventilation, or to assess performance of safety measures over a range of fires differing in size, duration and locations [3].

Tunnel fires, as fires in enclosures, are very complex in nature [6]. Their complexity arises from the fact that the physical and chemical processes (e.g., turbulence, combustion, radiation, etc) controlling fire and smoke development interact with each other and with the surroundings. Radiation can be a significant portion of the overall heat transfer in confined combusting flows, typically when temperatures are above 670K [3].

In fire science literature thermal radiation has been early recognized as an important and sometime dominant mode of heat transfer for medium and large scale fires. Indeed, it can determine the growth and spread of some type of fires [7,8]. Many authors [3,9–11] reported that radiative heat transfer can account for 20-40% of the heat output of a large fire. Combustion products such as CO_2 and H_2O, emitting energy in discrete bands, are the main radiation sources. Moreover, according to the review performed by Novozhilov [7], radiation due to luminous diffusion flames contributes significantly in lowering the flame temperatures. Finely dispersed soot particles act accordingly as individual minute black or gray body and emit continuously over a wide range of wavelengths. Soot, CO_2 and H_2O are responsible for more than 95% of the radiant absorption and emission [7]. Radiative heat transfer occurs between the