Analysis of the mechanical ventilation effect on the smoke layer height evolution in a road tunnel using a fire zone model

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Keywords

Tunnel, Fire, CFAST, Ventilation, Smoke layer height

Introduction

Although the frequency of fires in tunnels is statistically lower than in enclosed buildings, they can reach extreme temperatures much faster than in a typical enclosed space, leading to rapid smoke filling [1]. Advanced fire modelling approaches include Computational Fluid Dynamics (CFD) models and zone models [2–3]. CFD models are widely used in the field of performance-based fire safety design. In contrast, zone models are generally not suitable for simulating longitudinal compartments [4]. However, several zone models, such as CFAST [5], have been validated for linear structures like tunnels. Their main advantage over CFD models is computational speed, which makes them potentially suitable for tunnel fire modelling [1]. In terms of mechanical ventilation, critical airflow velocity and back-layering are crucial factors for smoke control in longitudinal tunnel ventilation [6]. The aim of this article was to analyse the mechanical ventilation effect on the smoke layer height evolution and simultaneously evaluate the capabilities of the zone model CFAST in terms of tunnel mechanical ventilation.

Methodology

The zone fire model CFAST [5] was used to analyse the influence of ventilation on the fire evolution in a road tunnel made of reinforced concrete. The tunnel is 500 m long and has an idealised rectangular cross-section, 10 m wide and 5 m high. A fire scenario involving a heavy goods vehicle located in the middle of the tunnel was considered. The tunnel was divided into 25 equal segments with a length-to-width ratio of 2:1, following recommendations from previous studies [7, 8]. The analysis included a case without mechanical ventilation and, subsequently, nine cases with mechanical ventilation using jet fans defined by their flow rates ranging from 10 to 90 m^3/s.

Results

The resulting graph depicts the smoke layer height above the floor throughout the entire length of the tunnel at time intervals of 5 and 15 (Fig. 1). It can be observed that different levels of mechanical ventilation have some impact, but in the sections located behind the middle segments, the conditions inside the tunnel worsen. As the flow rate of the fans increases, the smoke layer descends to floor level. Consequently, a safe smoke layer height above the floor for the evacuation of individuals, specifically a height of at least 2.5 m above the floor, is not guaranteed [1]. Although the zone model CFAST allows for tunnel fire modelling, the proper application of mechanical ventilation effects remains unclear, see also [7].

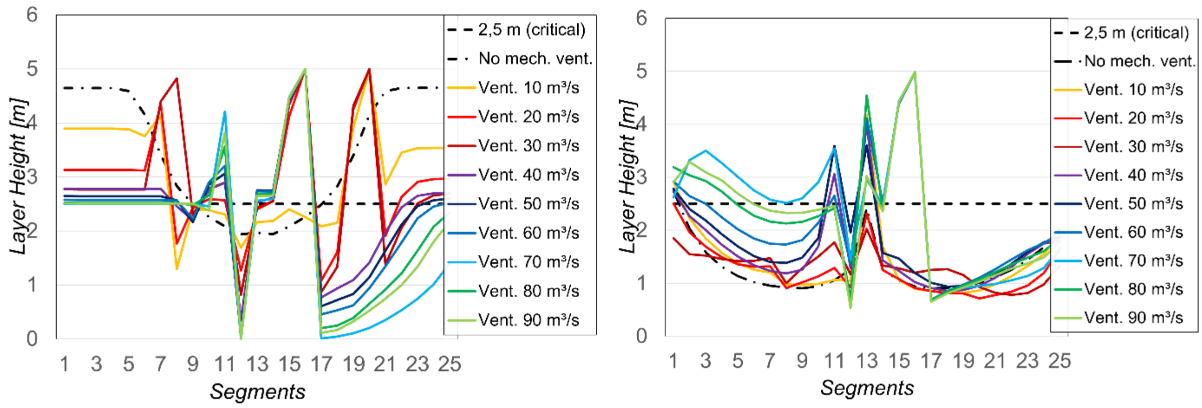

Fig. 1: Smoke layer height in individual segments, longitudinal cross-section of the tunnel in time of 5 minutes (left) and 15 minutes (right)

Summary

This paper aimed to analyse the influence of mechanical ventilation on the smoke layer height in a road tunnel using the CFAST zone model. Based on the results presented in this study, it is evident that modelling the complex ventilation conditions in tunnels using the CFAST software tool cannot be considered reliable and requires further investigation, particularly in comparison with CFD models.

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