

Accepted Manuscript

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PII: S0379-7112(16)30215-6

DOI: 10.1016/j.firesaf.2018.06.002

Reference: FISJ 2716

To appear in: *Fire Safety Journal*

Received Date: 15 December 2016

Accepted Date: 02 June 2018

Please cite this article as: Ying Zhen Li, Haukur Ingason, Discussions on critical velocity and critical Froude number for smoke control in tunnels with longitudinal ventilation, *Fire Safety Journal* (2018), doi: 10.1016/j.firesaf.2018.06.002

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Discussions on critical velocity and critical Froude number for smoke control in tunnels with longitudinal ventilation

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Abstract: Determination of critical velocity is a key issue for smoke control in any tunnel with longitudinal ventilation. The critical Froude model using single Froude number of 4.5 has for decades been widely used in engineering applications. This value was originally used by Danziger and Kennedy and they argued that the critical Froude number obtained by Lee et al. was in a range of 4.5 and 6.7 and therefore a conservative value of 4.5 was obtained. This paper explores the validity of using single critical Froude number of 4.5 by investigating the original sources and comparing it to recent research results. It was found that the value of 4.5 obtained in the original source corresponds to a large tunnel fire and it correlates well with data from other literature within a narrow range of large fire sizes. Using this value produces a significantly lower critical velocity for a wide range of fire sizes and therefore it is not conservative. The Froude number of 6.7 obtained by Lee et al. corresponds to another Froude number with a different definition and it is therefore not comparable with the value of 4.5. It is found that the use of a single value of 4.5 for the critical Froude number is not reasonable in calculation of the critical velocity for smoke control in tunnels with longitudinal ventilation.

Key words: tunnel fire, critical velocity, critical Froude number, longitudinal ventilation

Nomenclature			
A	tunnel cross-sectional area (m^2)	T_o	ambient temperature (K)
c_p	specific heat of air ($\text{kJ}/(\text{kg}\cdot\text{K})$)	T	average smoke temperature (K)
Fr_a	Froude Number far upstream	u_o	longitudinal velocity (m/s)
Fr_c	critical Froude Number	u_c	critical velocity (m/s)
g	gravitational acceleration (m/s^2)	u_c^*	dimensionless critical velocity
H	tunnel height (m)	W	tunnel width (m)
k	constant	<i>Greek symbols</i>	
$\dot{Q}$	total heat release rate (kW)	ρ_o	ambient density (kg/m^3)
$\dot{Q}^*$	dimensionless heat release rate	$\Delta\rho$	density difference (kg/m^3)
$\dot{Q}_c$	convective heat release rate (kW)		

1. Introduction

Determination of critical velocity for smoke control in tunnels plays a key role in emergency ventilation plans. The critical velocity is defined as the minimum longitudinal ventilation velocity to prevent reverse flow of smoke spreading upstream of the fire [1], see Figure 1. In other words, when the longitudinal velocity is greater than the critical velocity, there is no reverse flow or backlayering upstream of the fire. The critical velocity and backlayering length are important design parameters that have been investigated by many researchers [2-9]. At the evacuation stage in a tunnel with longitudinal

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