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Wavefront evolution of compression waves propagating in high speed railway tunnels

Honglin Wang, Bo Lei, Haiquan Bi*, Tao Yu

School of Mechanical Engineering, Southwest Jiaotong University, China

A R T I C L E I N F O

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A B S T R A C T

The amplitude of micro-pressure wave emitted from the exit portal of a high-speed railway tunnel is approximately proportional to the pressure gradient of the internal wavefronts approaching the portal. For long tunnels, the evolution during propagation is an important factor for estimating the pressure gradient in the exit wavefront. Moreover, the relationship between the entrance and exit states depends upon the conflicting influences of inertia and damping along the propagation. In this paper, the investigation is done to study the evolution of wavefronts with different initial waveforms and to assess the influence of friction and train speed in the process. This work is based on numerical simulations of wavefront propagation using a third-order monotonic upwind scheme for conservation laws and backed up by field measurements. Numerical analyses show that the wavefront evolution not only depends on the pressure amplitude and the maximum pressure gradient of the initial wavefront but also depends strongly on the shape and timing of the peak steepness of $\partial P/\partial t$. The predictions also demonstrate the existence of a critical tunnel length. For any particular train and tunnel entrance, the magnitudes of the micro-pressure waves increase with the tunnel length when this length is below the critical one and decrease with the tunnel length otherwise. The critical length decreases with the increase of the tunnel wall friction and the train speed.

1. Introduction

The emission of micro-pressure waves (MPWs) from the exit portal of high speed railway tunnels has become an important environmental problem. MPWs can create an unacceptable noise near the exit portal of tunnels and pose severe vibration risks to nearby housing structures. Moreover, MPWs may cause sonic booms. These issues are becoming extremely prominent with increasing train speeds, because MPWs are dependent on the cube of train speed (V^3). Whereas remedial measures requiring excessive cost are implemented, the effectiveness of countermeasures is perceived to be low because the wavefront evolves with the increase in propagation distance. Moreover, the amplitude of micro-pressure waves is approximately proportional to the pressure change rate of internal wavefronts approaching the exit portal [1–4]. The wavefront at the exit depends upon the initial wavefront generated by the train entering the tunnel and wavefront evolution inside the tunnel. Therefore, the wavefront evolution during propagation is essential to the prediction and control of MPWs.

The inertia of airflow inside the tunnel steepens the wavefront, and tunnel construction damping elongates it. Therefore, wavefront evolution is influenced by both. Fig. 1 shows the evolution of a wavefront as it propagates along a tunnel. For

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* Corresponding author. School of Mechanical Engineering, Southwest Jiaotong University, Chengdu 610031, China.
E-mail address: bhquan@swjtu.edu.cn (H. Bi).

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Nomenclature

c_p	constant pressure specific heat capacity (J/(kg K))
D	hydraulic diameter (m)
E	specific total energy (J/kg)
F_{tu}	tunnel cross-section area (m^2)
F_{tr}	train cross-section area (m^2)
f_s	steady friction coefficient
G	friction (N)
G_s	steady friction (N)
G_{us}	unsteady friction (N)
H	specific total enthalpy (J/kg)
M	Mach number
P	absolute gas pressure (Pa)
Pr	Prandtl number
q	heat transfer term between fluid and tunnel wall(J/kg)
R_{gas}	gas constant (J/(kg K))
R_t	blockage ratio
S_{tu}	tunnel cross-section perimeter (m)
T_{tun}	tunnel wall temperature (K)
T	air absolute temperature (K)
t	time coordinate (s)
u	x-direction velocity components (m/s)
V	train speed (km/h)
x	distance along the tunnel length (m)
$W(\theta)$	weighting function
$(\partial P/\partial t)_{\max}(x)$	maximum pressure gradient of wavefront at distance x (kPa/s)
$(\partial P/\partial t)_{\max}(0)$	maximum pressure gradient of initial wavefront (kPa/s)
$\Delta P(x)$	pressure rise of wavefront at the distance x (kPa)
$\Delta P(0)$	pressure rise of initial wavefront (kPa)

Greek characters

ρ	gas density ($\mathrm{kg/m}^3$)
ν	kinematic viscosity (m/s)
γ	ratio of principal specific heat capacities
ξ	distortion rate
k	attenuation rate
$\varepsilon_{\mathrm{us}}$	unsteady friction factor

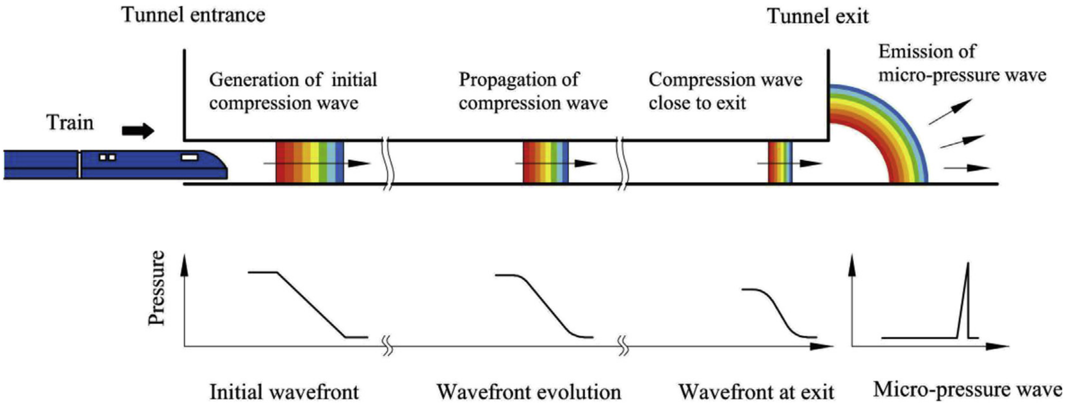

Fig. 1. Wavefront evolution and emission of micro-pressure waves.