Tunnelling and Underground Space Technology 80 (2018) 211–221

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

Numerical studies on the radiation of train-tunnel impulse waves

Guang Zhang[a], Dong Hyeon Kim[b], Heuy Dong Kim[a,*]

[a] Department of Mechanical Engineering, Andong National University, Andong, Republic of Korea
[b] Senior Researcher ICT Research Team, Korea Railroad Research Institute (KRRI), Republic of Korea

ARTICLE INFO

Keywords:
High-speed train tunnel
Radiation of impulse wave
Coefficient of effective radiation solid angle
Unsteady compressible flow

ABSTRACT

An impulse wave is always discharged from the exit of a train tunnel when a weak compression wave induced by a moving high-speed train at the tunnel entrance propagates outside of the tunnel exit. An impulse wave is a micro-pressure wave, which leads to environment problems such as noise, vibration and other structural damages in the vicinity of the tunnel exit. Currently, due to the development of the optimization and acceleration systems of the high-speed train, the train speed becomes much higher than before and environmental problems become more serious as well. Therefore, it is significantly important to find effective methods to control and reduce magnitudes of impulse waves discharged from the tunnel exit. In the present study, numerical simulations were carried out to investigate the generation and propagation of impulse waves discharged from the exit of a model tunnel. Weak compression waves with different pressure gradients were assumed at the tunnel entry for investigating the relationship between the compression wave and the impulse wave radiated from the tunnel exit. Several tunnel exit geometries with and without a flange at the exit portal of the tunnel were simulated to check their effects on the radiation of impulse waves. Coefficient of effective radiation solid angle indicating the effects of the surrounding environment near the tunnel exit was discussed in-depth. The comparison was made in terms of the magnitudes of impulse waves and coefficients of effective radiation solid angle at different boundary conditions.

1. Introduction

As a high-speed train moves through a train tunnel, the air around the train nose is compressed and a compression wave is induced. When the compression wave moves outside of the tunnel exit, an impulse wave is discharged from the tunnel exit and propagates to the downstream as shown in Fig. 1. In addition, an expansion wave is also discharged and propagates to the upstream. An impulse wave is a micro pressure wave, which is regarded as a sound noise that leads to environmental problems and vibrations. Local residents suffer from the sharp noise close to the exit of a train tunnel and feel the strong vibration as well when the high-speed passes by. Previously, due to the low speed of the train, impulse waves discharged from the tunnel exit are extremely weak micro-pressure wave and researchers did not focus on this issue. With the development of the technology of the high-speed train, the speed of the train becomes higher and higher, which leads to more serious environmental problems. Recently, many researchers start paying more attention to investigate the impulse wave discharged from the exit of the high-speed train tunnel.

The impulse wave is induced by a weak compression wave generated inside the train tunnel, so it is significantly important to find out the relationship between the entry compression wave and the impulse wave at the tunnel exit. This makes practical meanings in decreasing the magnitude of the impulse wave. The relationship between the entry compression wave and the impulse wave discharged from the tunnel exit was investigated in-depth based on aeroacoustic theories (Matsuo and Aoki, 1991; Kashimura et al., 1996; Aoki and Matsuo, 2000; Baron et al., 2006). Both theoretical and experimental studies were carried out to find out the detailed expression on this relation. The maximum magnitude of an impulse wave was derived to linearly depend on the maximum pressure gradient across the entry compression wave which affects its wave length as well. Therefore, by changing the form of the entry compression wave, the maximum magnitude and the wave length of an impulse wave can be effectively controlled at the exit of a train tunnel. Based on the above calculation, the methods which are able to change the form of the entry compression wave have been investigated in details (Howe, 1999; Howe et al., 2000; Bellenoue et al., 2002). Parameters such as the train nose and body, the entry tunnel portal, the tunnel hood, the baffled wall and the structure of the tunnel were observed to affect the generation and form of the entry compression wave deeply. The optimization on those parameters is greatly concerned by countries that have advanced technologies in developing the high-speed trains such as Germany, Japan and China.

* Corresponding author.
E-mail address: kimhd@anu.ac.kr (H.D. Kim).

https://doi.org/10.1016/j.tust.2018.06.020
Received 29 January 2018; Received in revised form 20 April 2018; Accepted 26 June 2018

Nomenclature

A	area of cross-section
c	sound speed
D	tunnel diameter
e	open-end correction
g	angle
L	location behind the tunnel exit
M	mach number
P	pressure
R	radius
t	time
V	train velocity
X	axial distance
θ	angle
Φ	coefficient of effective radiation solid angle

Subscripts

C	compression wave
f	flange
C, max	maximum pressure gradient across a compression wave
I, max	maximum magnitude of an impulse wave
S	shock wave

In order to investigate the impulse wave discharged from the tunnel exit simply, a shock tunnel was used to generate the entry compression wave (Kim et al., 2001; Kim and Seroguchi, 1999; Raghunathan et al., 2002; Kim et al., 2003). Experimental studies were carried out on the generation and propagation of the impulse wave induced by entry compression waves with different Mach numbers. The maximum magnitude of an impulse wave was obtained to be affected by Mach number of the entry compression wave and the location where the impulse wave reached. Due to that entry compression waves induced by a shock wave were strong shock waves, they were observed to determine impulse waves radiated from the tunnel exit non-linearly. The impulse wave induced by a strong compression wave should be

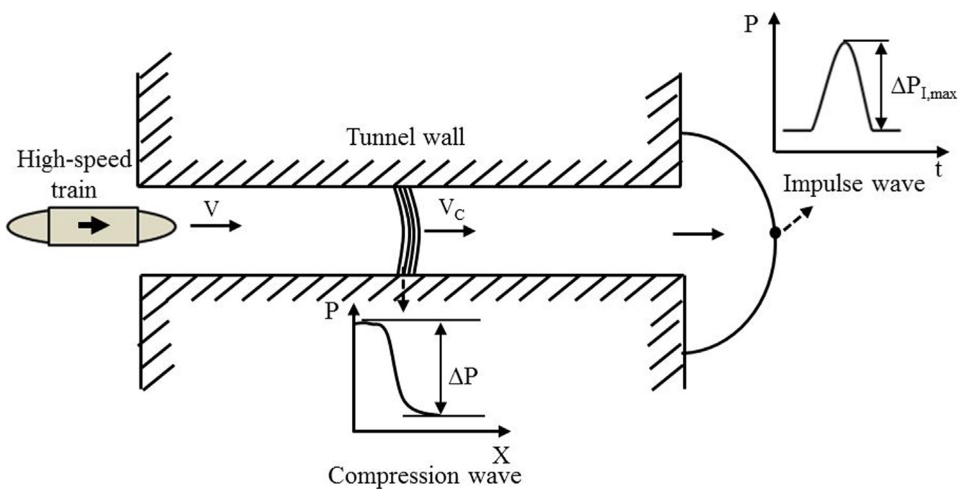

Fig. 1. Schematic of an impulse wave discharged from the exit of a high-speed train tunnel.

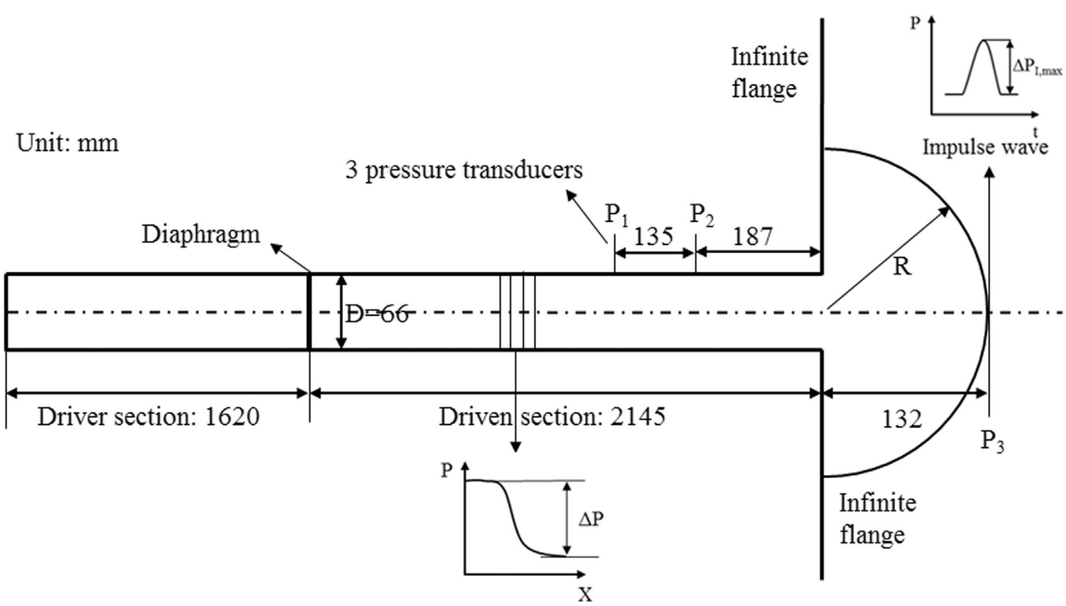

Fig. 2. Experimental setups used for validating CFD methods.