Investigation into noise attenuation strategies within train tunnels

Paul Williams (1), Mahmoud Karimi (1), Shahrokh Sepehrirahnama (2), Jorge Reverter Garcia (2), Briony Croft (3), Dave Hanson (3), Aaron Miller (3) and Jeffrey Parnell (1,4)

(1) Centre for Audio, Acoustics, and Vibration, University of Technology Sydney, Ultimo, New South Wales, Australia
(2) JHA Consulting Engineers, Sydney, New South Wales, Australia
(3) Acoustic Studio Pty Ltd, Stanmore, New South Wales, Australia
(4) Sydney Metro, New South Wales, Australia

Abstract - Across Australia, cities are extending their public transportation systems through additional tunnels and metro systems. The sound energy generated by metro trains operating in tunnels is mainly confined within the tunnel by the tunnel walls, causing higher noise levels within the carriages than comparable above-ground networks. This work investigates in-tunnel noise using a computational model of the metro tunnel, with the objective of developing a tool that can be used to investigate a range of novel mitigation measures. A numerical model is developed that uses the semi-analytical finite element (SAFE) method to provide a novel modal-based approach towards tunnel noise modelling. The first stage of this method involves performing a two-dimensional finite element eigenvalue decomposition over the cross-section of the tunnel to determine the characteristics of each tunnel mode. Propagation of sound pressure along the length of the tunnel is then implemented analytically, avoiding the computational expense of three-dimensional standard finite element methods. For simplicity, the carriage can be included as a rigid body, and the variations of the tunnel cross-section are neglected. Predictions are compared to the measured in-tunnel noise generated using a known input source. Numerical and experimental studies will allow for the investigation of cost-effective noise reduction solutions that may be applied to current and future rail projects.

1 INTRODUCTION

Designing a noise control solution generally begins with modelling the system to determine the optimum location, and form, of the mitigation. Train tunnels can present a problem with this approach due to their large dimensions, which can be a challenge to model efficiently. Ray tracing methods are popular due to their relative computational efficiency, however they simplify propagation by assuming that the sound pressure propagates as rays (Siltanen, Lokki, & Savioja, 2010). They therefore lack wave-based phenomena such as diffraction. Recently, Li et al. (Li, Thompson, & Squicciarini, 2021) proposed an efficient 2.5D acoustic finite element method to investigate the sound pressure level on the surface of a train carriage. Since train tunnels share some common features with ducted systems, such as their long, uniform lengths and approximately rigid walls, common duct acoustics techniques could also be applied. For example, the SAFE method was applied to predict the transmission loss of HVAC silencers with complex cross-sections by Kirby et al. (Kirby, Williams, & Hill, 2014). In this investigation, the 3D SAFE method will be applied to investigate the effect of noise propagation on in-tunnel noise levels.

2 SOUND PRESSURE LEVEL WITHIN THE TUNNEL

The tunnel, which is approximately 6 m across, will be assumed to be straight with a constant cross-section and infinite length. The cross-section of the tunnel is illustrated in Figure 1. A rigid body in the tunnel represents a carriage which results in an annular fluid domain.

While tunnels are three-dimensional objects, the length of the tunnel can cause some numerical models to become computationally expensive. The use of 2D models to simplify the problem, or computationally efficient 3D models, may therefore be attractive. In this section, the sound pressure level within a tunnel is predicted using the 3D SAFE method. This is compared to a prediction of the tunnel's cross-section created using a 2D finite element method (FEM). The wheel-rail interaction is represented using a series of acoustic monopoles and dipoles situated near the rails.

The sound pressure level within the tunnel at 343 Hz is illustrated in Figure 1. The 2D prediction results in a sound pressure level that is somewhat uniform across the cross-section. This is caused by the acoustic energy being trapped within the rigid tunnel. The 3D model shows a significant difference in the predicted sound pressure levels across the tunnel's cross-section. The sound pressure level is highest close to the sound sources underneath the carriage, as expected. There is then a reduction in amplitude as it propagates around the carriage due to the ability of the acoustic energy to escape along the length of the tunnel.

3 CONCLUSIONS

The difference in the distribution of the sound pressure level across the tunnel may lead engineers to different conclusions as to where noise control measures should be placed within a tunnel to achieve optimum transmission loss. Using the 2D model it may be concluded that absorptive panels may be placed anywhere on the tunnel wall and be equally effective. However, the 3D model predicts that the sound pressure level is highest near the noise sources. Using the more accurate 3D model leads to the different conclusion that noise control could be more effective if it is instead located close to the noise sources.

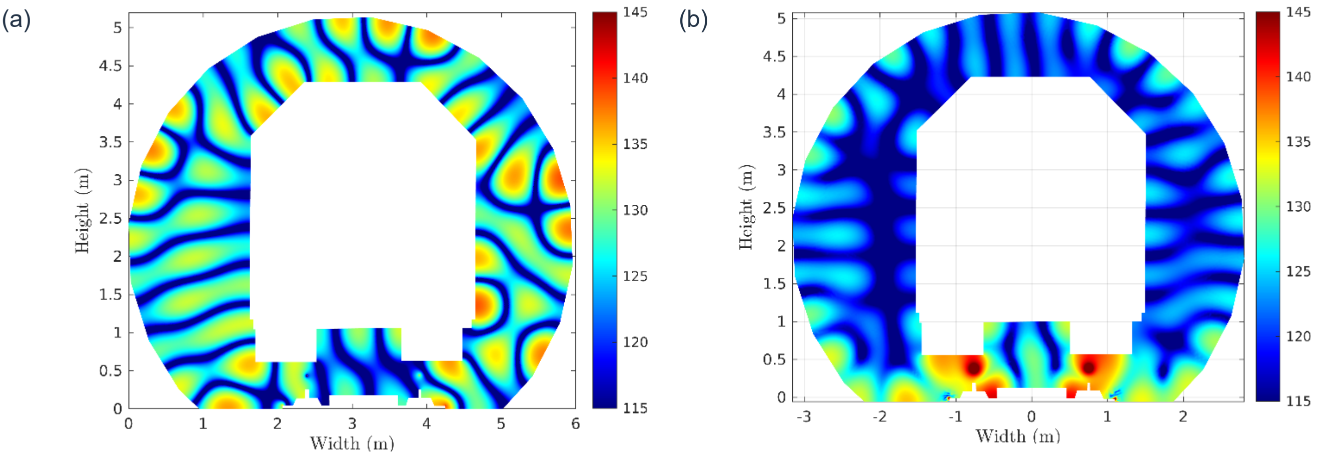

Figure 1. Sound pressure level (dB, ref. $2x10^{-5}$ Pa) at 343 Hz within the tunnel when excited by sources representing the wheel-rail interaction and with a rigid train carriage. (a) 2D FEM method; (b) 3D SAFE method at the source plane.

REFERENCES

Kirby, R., Williams, P. T., & Hill, J. (2014). A three dimensional investigation into the acoustic performance of dissipative splitter silencers. *The Journal of the Acoustical Society of America*, 2727-2737.

Li, H., Thompson, D., & Squicciarini, G. (2021). A 2.5D acoustic finite element method applied to railway acoustics. *Applied Acoustics*, 108270.

Siltanen, S., Lokki, T., & Savioja, L. (2010). Rays or Waves? Understanding the Strengths and Weaknesses of Computational Room Acoustics Modeling Techniques. *Proceedings of the International Symposium on Room Acoustics, ISRA 2010.*