INVESTIGATING THE EFFECT OF UNDER SLEEPER PADS AND BALLAST MATS IN ATTENUATION OF TRAIN INDUCED GROUND VIBRATIONS

Marasinghe Mudiyanselage Geeshan Chamodya Marasinghe

248075K

Master of Science (with Major Component of Research)

Department of Civil Engineering
Faculty of Engineering

University of Moratuwa
Sri Lanka

December 2025

INVESTIGATING THE EFFECT OF UNDER SLEEPER PADS AND BALLAST MATS IN ATTENUATION OF TRAIN INDUCED GROUND VIBRATIONS

Marasinghe Mudiyanselage Geeshan Chamodya Marasinghe

248075K

Thesis submitted in partial fulfillment of the requirements for the degree
Master of Science (with Major Component of Research)

Department of Civil Engineering
Faculty of Engineering

University of Moratuwa
Sri Lanka

December 2025

DECLARATION

I declare that this is my own work and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: Date: 27/12/2025

The above candidate has carried out research for the PhD/MPhil/Masters thesis/dissertation under my supervision. I confirm that the declaration made above by the student is true and correct.

Name of Supervisors: Dr. H.G.H. Damruwan
Prof. C. S. Lewangamage

Signature of the Supervisors:

…………………………..
Dr. H. G. H. Damruwan Date: 29/12/2025

Prof. C. S. Lewangamage Date: 29/12/2025

DEDICATION

This thesis is dedicated to all those who offered unwavering support and encouragement throughout my academic journey. This achievement is not mine alone, it is also a reflection of the compassion, guidance, and solidarity of the remarkable individuals who stood by me during this transformative period.

To my principal supervisor, Dr. H. G. H. Damruwan, I express my heartfelt gratitude. Your insightful guidance, generous mentorship, and continuous encouragement have been instrumental in shaping this research. I would also like to extend my sincere thanks to my co-supervisor, Prof. C. S. Lewangamage, for providing valuable guidance on various aspects throughout this study.

I lovingly dedicate this work to my family, whose constant encouragement and patience have been my greatest strength. I also dedicate this thesis to my friends and research colleagues for their motivation, support, and positivity throughout this endeavor. Finally, this work is for anyone who is passionate about learning and committed to the pursuit of knowledge through research.

Above all, I dedicate this achievement to the people of Sri Lanka, whose contributions sustain the nation's free education system and made my academic journey possible.

ACKNOWLEDGEMENT

First and foremost, I extend my heartfelt gratitude to my principal supervisor, Dr. H.G.H. Damruwan, from the Department of Civil Engineering at the University of Moratuwa, for his steadfast guidance, encouragement, and insightful mentorship throughout this research. His expertise, patience, and unwavering support have been pivotal in shaping the direction and quality of this thesis.

I also wish to sincerely thank my co-supervisor, Prof. C. S. Lewangamage, for providing valuable guidance on various aspects throughout this study. I am grateful to the technical officer and supporting staff at Structural Dynamics and Health Monitoring Lav for their assistance during the field studies.

I also wish to sincerely thank the Progress Review Committee, especially Dr. Lakshitha Fernando, for his critical feedback, thoughtful suggestions, and consistent support, which helped to enhance the depth and clarity of this work.

I am also thankful to the academic staff of the Department of Civil Engineering, University of Moratuwa, including Prof. H.R. Pasindu, the MSc Research Coordinator, and especially the academic staff members of the Structural Division, for their continued academic guidance and encouragement throughout the MSc program.

To my fellow researchers and colleagues, thank you for your collaboration, encouragement, and knowledge-sharing that enriched this journey and made it a truly collective effort. Finally, I am deeply grateful to my family and friends for their constant motivation, patience, and unwavering belief in me. Their love and emotional strength carried me through every challenge I faced along this path.

ABSTRACT

Increasing train speeds and axle loads in modern railway systems have intensified the problem of train-induced ground-borne vibration. Vibration generated at wheel–rail interface propagates through the track, ballast, and subgrade to nearby structures, causing potential discomfort, structural damage, and functional disruptions. Out of the available mitigation measures, under sleeper pads (USP) and ballast mats (BM) are very feasible methods that can be adapted in urban areas where the reserved area for track is limited. However, the complex interaction between these mitigation layers, the track system, and heterogeneous soil conditions remains insufficiently understood. This research addresses that gap through a comprehensive numerical investigation combining model validation and parametric analysis.

A three-dimensional finite element (FE) model of a coupled train–track–soil system was developed using the ABAQUS FE software to simulate time-domain vibration propagation. The model incorporated layered track components, rails, sleepers, ballast, sub-ballast, and subgrade, and implemented viscous boundaries to eliminate reflections from the truncated domain. A simplified three-car moving-load train model was adapted to accurately capture the vibration generation mechanisms. Model validation was performed against established field experiments from literature using several key metrics.

Following validation, a parametric study was designed to quantify the influence of USP and BM thickness and stiffness under two representative ground conditions, soft soil (V_s = 200 m/s) and stiff soil (V_s = 400 m/s). The chosen parameters, consistent with international standards and guidelines, included USP thicknesses of 8, 10, and 15 mm; stiffnesses of 0.15, 0.25, and 0.35 N/mm^3; and BM thicknesses of 15, 23, and 30 mm with stiffnesses of 0.05, 0.09, and 0.22 N/mm^3. Vibration attenuation was evaluated for near-field (0–10 m) and far-field (>10 m) receivers using Insertion Loss (IL) and frequency-dependent 1/3-octave band spectra.

Both USPs and BMs were found to be significantly more effective in stiff soil compared to soft soil, achieving stronger vibration reduction and extending attenuation further into the far field. In soft soil, soft or thick USPs can trigger near-field amplification due to soil–pad resonance, while stiff soil reliably delivers stable mitigation. Thicker and softer BMs provide the best performance, especially in mid-frequency bands (30–80 Hz) critical for human perception. Overall, vibration control is strongest near the track (within 10 m) and decreases with distance, with BMs offering superior and more consistent attenuation than USPs across all conditions.

The study provides clear guidance for choosing between USPs and BMs under different ground conditions, and show that simple, validated FE models can support reliable design decisions for urban rail vibration control.

Keywords: Train-induced ground vibration, Under sleeper pads, Ballast mats, Vibration attenuation

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BM	Ballast Mat
CEA	Central Environmental Authority
FE	Finite Element
FEM	Finite Element Method
HST	High-Speed Train
IL	Insertion Loss
ISO	International Organization for Standardization
P-wave	Primary (compressional) seismic wave
PPV	Peak Particle Velocity
S-wave	Secondary (shear) seismic wave
USP	Under Sleeper Pad
UIC	International Union of Railways
V_{rms}	Root-Mean-Square Velocity
V_s	Shear-wave velocity
V_p	Compressional-wave velocity