

INVESTIGATION OF GROUND VIBRATIONS DUE TO MOVING TRAINS

Phapetha Thadsanamoorthy

208041R

Degree of Master of Science

Department of Civil Engineering

University of Moratuwa

Sri Lanka

July 2023

INVESTIGATION OF GROUND VIBRATIONS DUE TO MOVING TRAINS

Phapetha Thadsanamoorthy

208041R

Thesis submitted in partial fulfilment of the requirements for the degree Master of
Science in Civil Engineering

Department of Civil Engineering

University of Moratuwa

Sri Lanka

July 2023

DECLARATION OF THE CANDIDATE & SUPERVISOR

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a 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.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature:

Date: 09/07/2023

The above candidate has carried out research for the Masters under my supervision

Name of the supervisor: Dr. H. G. H. Damruwan

Signature of the supervisor:

Date: 10/07/2023

Name of the supervisor: Prof. C. S. Lewangamage

Signature of the supervisor:

Date: 10/07/2023

ABSTRACT

This research focuses on the assessment of train-induced ground vibrations through experimental analysis and the development of a Finite Element (FE) prediction model. The study aims to evaluate the intensity of vibrations caused by trains and understand their effects on different soil types and train speeds.

A vibration sensing device named "VIBSEN" was developed for the measurement of ground vibrations. Experimental data were collected at 3m intervals from the centreline of the railway track and processed using MATLAB software. The accuracy of the device was confirmed through gravity calibration and comparison with a vibrometer. Based on the experimental study conducted at a specific site, it was determined that the minimum safe distance from the centreline of the track is approximately 10m when two trains cross simultaneously and approximately 6m when considering the passage of a single train. It should be noted that these recommendations are specific to the soil profile at the experimental site and may vary depending on subgrade soil type and parameters.

The FE prediction model, developed using MIDAS GTS NX FE software, was validated using experimental results from the study and further compared with literature data. The model successfully predicted train-induced ground vibrations, demonstrating its applicability. Parametric analysis was conducted to investigate the effects of soil type and train speed on vibration intensity, including the identification of resonance frequencies and critical velocities. The findings of the study indicate that vibration intensity varies significantly depending on the soil type, with lower intensities observed for soils with higher elastic moduli. Additionally, the study highlighted that vibration intensity increases with train speed, and certain speed levels may lead to a sudden increase in intensity due to resonance effects. The resonance frequency was found to be influenced by the elastic modulus of the subgrade soil.

Overall, this study provides valuable insights into train-induced ground vibrations and offers recommendations for safe distances from the track centreline. The developed VIBSEN device and FE prediction model offers reliable tools for future investigations and allow for parametric studies considering different soil properties, train loads, and speeds. These findings contribute to mitigating risks, minimizing structural failures, and reducing hazards associated with prolonged exposure to vibrations.

Keywords: Train-induced ground vibration; VIBSEN device; Peak Particle Velocity (PPV); Finite Element (FE) prediction model.

ACKNOWLEDGEMENT

I wish to acknowledge the financial support provided by the Senate Research Committee (Grant - SRC/LT/2020/17), University of Moratuwa, Sri Lanka to undertake this research. In addition to that, I take this opportunity to express my sincere gratitude to the individuals who have guided me and supported throughout the entire journey to successfully finish this research study.

I would like to extend my heartiest gratitude to my supervisors Dr. H. G. H. Damruwan, Senior lecturer, Department of Civil Engineering, University of Moratuwa, and Prof. C. S. Lewangamage, Professor, Department of Civil Engineering, University of Moratuwa, for the immense trust, support and guidance provided throughout the entire duration to successfully complete this research.

My special thanks to Prof. M. T. R. Jayasinghe and Prof. J. C. P. H. Gamage for the valuable advice and comments given in the progress presentations. My sincere thanks to Prof. (Mrs). C. Jayasinghe, Head, Department of Civil Engineering, University of Moratuwa, for her immense support in providing necessary facilities and provisions in completing this study. I am indebted to give my gratitude to Eng.K.Pirunthan for his immense support in enhancing my understanding and knowledge in electronic device development.

Furthermore, my sincere gratitude to the staff of Department of Railways, Sri Lanka, the academic and non-academic staff of the Department of Civil Engineering, University of Moratuwa for their guidance and support to complete this research study. I'm grateful for all the previous researchers for undertaking successful research and making them available for the upcoming researchers. Last but not least, I am extending my humble gratitude for all my friends and colleagues for supporting me in all the ways they could.

Phapetha Thadsanamoorthy,
Department of civil engineering,
University of Moratuwa

TABLE OF CONTENTS

Declaration of the candidate & supervisor.....	i
Abstract	ii
Table of contents	iv
List of figures	viii
List of tables.....	x
List of abbreviations	xi
List of appendices	xi
1. Introduction.....	1
1.1 Background	1
1.2 Problem statement	4
1.3 Aim and objectives.....	5
1.4 Significance of the Research	6
1.5 Arrangement of the Thesis	6
2. Literature review	9
2.1 Introduction	9
2.2 Influence of ground profile in the intensity of train induced vibration	10
2.3 Approaches of Vibration Analysis	12
2.3.1 Experimental analysis	12
2.3.2 The numerical FE prediction model	14

2.3.3	Track modelling	17
2.3.4	Track-soil modelling	18
2.4	Parameters influencing the railway vibration intensity.....	18
2.5	Noise and vibration	20
2.6	Effects of vibration.....	21
2.6.1	On buildings.....	21
2.6.2	On human beings	22
2.7	Summary	22
3.	Methodology	23
3.1	Introduction	23
3.2	Development of VIBSEN device	23
3.2.1	Components of the accelerometer and functions	24
3.2.2	Functionality of the VIBSEN device	26
3.3	Data analysis using MATLAB	27
3.4	Field experimental analysis.....	30
3.4.1	Experimental location	30
3.4.2	Field experimental setup	32
3.4.3	Soil sampling and classification.....	32
3.4.4	Speed survey.	34
3.4.5	Data acquisition and processing.....	35

3.4.6	Problems encountered in field experiment.....	35
3.5	FE modelling using MIDAS GTS NX software package	36
3.5.1	Coupled model	36
3.5.2	The components of the FE model	37
3.5.3	Elements, nodes, and mesh size	38
3.5.4	Vehicular load and load distribution.....	39
3.5.5	Damping.....	40
3.5.6	Boundary condition.....	40
3.5.7	Material properties for FE model.....	40
3.5.8	Material behaviour	42
3.6.	Chapter Summary.....	43
4.	Results.....	44
4.1	Introduction	44
4.2	Gravity calibration of VIBSEN device	44
4.3	Calibration of VIBSEN device with vibrometer	45
4.4	Field Experimental results.....	46
4.4.1	Soil investigation	46
4.4.2	Experimental result of VIBSEN device for a train travelling with a speed of 63.7 km/h (17.7 m/s).....	47
4.4.3	Analysis of experimental data considering the speed of the train.....	49

4.4.4	Analysis of the variation in vertical PPV when two trains cross at the same time	49
4.4.5	Identifying the safe distance using standard guidelines.....	51
4.5	Validation of the FE model	53
4.5.1	Comparison of field experimental results and FE simulation results.....	53
4.5.2	Comparison of field Experimental results of Degrande & Schillemans (2001) with the FE simulation results.....	55
4.6	Parametric analysis using the FE prediction model.	59
4.6.1	Analysis of the influence of soil type on the vibration intensity	61
4.6.2	Analysis of the influence of speed on vibration intensity.....	62
4.7	Summary	67
5.	Conclusion and Recommendation	69
5.1	Conclusion.....	69
5.2	Recommendation for future works.....	70
	References.....	72
	Appendices.....	81

LIST OF FIGURES

Figure 2.1: Vertical vibration levels generated due to near and far train passages....	11
Figure 2.2: Main contribution of dynamic vehicle/track and soil interactions	19
Figure 3.1: VIBSEN device	26
Figure 3.2: Acceleration along (a) X direction, (b) Y direction and (c) Z direction at 3m from the centerline of the railway track.....	27
Figure 3.3: Vertical acceleration-time history variation	29
Figure 3.4: Vertical velocity-time history variation.....	29
Figure 3.5: Vertical velocity-frequency history variation.....	29
Figure 3.6: Vertical velocity - frequency analysis at 3 m, 6 m, 9 m, and 12 m.....	30
Figure 3.7: Experimental location view 1	31
Figure 3.8: Experimental location view 2.....	31
Figure 3.9: Plan view of the device location and railway track.....	32
Figure 3.10: Soil sample obtained from the test location.	33
Figure 3.11: Particle size distribution of the soil sample.....	34
Figure 3.12: Fine meshed segment used for detailed analysis.....	37
Figure 4.1: Vertical acceleration of the VIBSEN device.....	45
Figure 4.2: Measured data from VIBSEN device and vibrometer.....	46
Figure 4.3 : Particle size distribution-Dry sieve analysis	47
Figure 4.4: Vertical velocity-time history variation for the train travelling at a speed of 63.7km/h (17.7 m/s).....	48

Figure 4.5 : Acceleration - time history variation for the train travelling at a speed of 63.7km/h (17.7 m/s)- VIBSEN device.....	48
Figure 4.6: Variation of vertical PPV with the distance from the railway track	49
Figure 4.7: Variation of vertical PPV with distance under two scenarios	50
Figure 4.8 : Comparison of the acceleration-time history variation at 3 m	53
Figure 4.9: Comparison of the acceleration-time history variation at 6 m	54
Figure 4.10: Comparison of the acceleration-time history variation at 9 m	54
Figure 4.11: Comparison of the acceleration-time history variation at 12 m	55
Figure 4.12: Comparison of Vertical PPV – time history variation at 4m	56
Figure 4.13: Comparison of Vertical PPV – time history variation at 6m	57
Figure 4.14: Comparison of Vertical PPV – time history variation at 8m	58
Figure 4.15: Comparison of Vertical PPV – time history variation at 12m	58
Figure 4.16 : Deviation of FE results with literature data.....	59
Figure 4.17: Variation of vertical PPV with the elastic modulus of the selected soil types for a train travelling at 45m/s	62
Figure 4.18: Variation of vertical PPV with speed for Dense sand with elastic modulus of 80MPa.....	63
Figure 4.19: Variation of vertical PPV with speed for hard clay with elastic modulus of 60MPa.....	64
Figure 4.20: Variation of vertical velocity with frequency for the train travelling at speed 85m/s on hard clay	64

Figure 4.21: Variation of vertical velocity with frequency for the train traveling at 120 m/s on hard clay	65
Figure 4.22: Variation of vertical velocity with frequency for the train traveling at 150 m/s on hard clay	65
Figure 4.23: Variation of vertical PPV with speed for medium sand and gravel having $E=120\text{GPa}$	66
Figure 4.24: Variation of Vertical PPV with speed for soft clay soil having $E= 20\text{MPa}$	66
Figure 4.25: Variation of vertical velocity with frequency for the train traveling at 85 m/s on soft clay ($E=20\text{MPa}$).....	67
Figure 4.26: Variation of vertical velocity with frequency for the train traveling at 85 m/s on dense sand ($E=80\text{MPa}$).....	67
Figure 4.27: Variation of vertical velocity with frequency for the train traveling at 85 m/s on medium gravel and sand ($E=120\text{MPa}$).....	68

LIST OF TABLES

Table 1-1: Influence of train type in vibration	3
Table 3-1: Sieve analysis test results of the soil sample	33
Table 3-2: Primary and Secondary wave velocity of soil	39
Table 3-3: Material properties used in the FE analysis.....	41
Table 4-1: Calibration results of VIBSEN device and vibrometer	45
Table 4-2: Vertical PPVs obtained from the experiment under two scenarios: (a) when two trains cross simultaneously, and (b) when a single train passes at a high speed	50
Table 4-3: Maximum allowable vibration level for building types	51

Table 4-4: Variation between FE simulation results and literature data.....	59
Table 4-5: Material properties of different soil types	60

LIST OF ABBREVIATIONS

FE – Finite Element	
FEM – Finite Element Model	
SHM – Structural Health Monitoring	
HST – High-speed train	
LRT – Light rail transit	
PPV – Peak Particle Velocity	
TGV – Train à Grande Vitesse	

LIST OF APPENDICES

Appendix A – Matlab code for signal processing	81
Appendix B – Borehole report of the locations at the vicinity of field test.....	85
Appendix C – Intensity of vibration during railway passage from the experimental analysis.....	87
Appendix D: The schematic diagram of a) STEVAL-MKI180V1 sensor and b) Raspberry Pi.....	91