Track substructure inclusions for reducing the risk of mud pumping in heavy haul tracks

by Joseph Arivalagan

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Doctor of Philosophy

under the supervision of Professor Cholachat Rujikiatkamjorn and Distinguished Professor Buddhima Indraratna

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Joseph Arivalagan, declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Civil and Environmental Engineering/Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution.

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Joseph Arivalagan,

02 December 2022.

I would like to dedicate my thesis to my beloved parents

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

ε_a - Cyclic axial strain

N – Number of cycles

N_c - Critical number of cycles

f - Frequency

O_f - Filtration opening size (f%)

d_f - Filament diameter (geotextile)

n - Porosity

t_{GT} – Thickness of the geotextile

μ_{GT} - Mass per unit area of the geotextile

ρ_f - Density of the fibres

i_{LG} – Hydraulic gradient across a soil thickness (L) and the geotextile

i_s – Rereference gradient in the soil

γ_d - Dry density

D_x - Soil particle size in mm for which x% of the soil is finer

C_u - Coefficient of uniformity of the subgrade soil

k_H - Horizontal permeability

k_V – Vertical permeability

O_{95} - Apparent opening size of geotextile filter

K_a - Reduction factor considering the effect of loading and partial clogging (geotextiles)

m_{vr} - Coefficient of volume compressibility

K_S - Hydraulic conductivity of the soil

K_{GS} - Hydraulic conductivity of a soil/geotextile composite

S_r - Degree of Saturation

V_w - Volume of water

V_v - Volume of voids

P_a' - Average contact pressure at the sleeper and the ballast interface

P_d - Design wheel load incorporating dynamic effects

P_s - Static wheel load

D_w - Diameter of the wheel

$\emptyset$ - Dimensionless impact factor (>1.0).

F - Factor depending on the type of sleeper and the track maintenance

U_h - Average degree of consolidation

T_h – Time factor

q_r - Maximum rail seat load

LIST OF ABBREVIATIONS

- ADR - Amplitude Domain Reflectometry
- AOS - Aperture Opening Size
- BDT – Basic Dynamic Test
- BFI - Ballast Fouling Index
- CL - Low Plasticity Clay
- CPT - Cone Penetration Test
- CSL - Critical State Line
- CSR - Cyclic Stress Ratio
- CSRc - Critical Cyclic Stress Ratio
- DBPF - Dirty Ballast Pumping Failure
- DFA - Dynamic Filtration Apparatus
- DFT - Dynamic Filtration Test
- EARS - Energy Absorbing Rubber Seam
- EPF - Erosion Pumping Failure
- EPP/EPWP - Excess Pore Water Pressure
- EPPG - Excess Pore Pressure Gradient
- FE - Finite Element
- FI - Fouling Index
- GPR - Ground Penetration Radar
- GR - Gradient Ratio
- HCR - Hydraulic Conductivity Ratio
- HS - Hardening Soil
- ICS - Instrumented Control Section
- LL - Liquid Limit
- LVDT - Linear Variable Differential Transformer
- MC - Mohr-Coulomb
- MP - Miniature Pressure Transducer
- NC - Normally Consolidated
- OC - Over Consolidated
- OCR – Over Consolidation Ratio
- OMC - Optimum Moisture Content
- P - Body Pressure Transducer

- PF - Percent Fouling
- PI - Plastic Index
- PL - Plastic Limit
- PP - Percent Passing
- PSD - Particle Size Distribution
- PVC - Percentage Void Contamination
- PVD - Prefabricated Vertical Drains
- RC – Relative Compaction
- RIBS - Rubber Intermixed Ballast System (RIBS)
- SPT – Standard Penetration Test
- SS – Soft Soil
- USCS - Unified Soil Classification System
- VCI - Void Contamination Index
- VWC - Volumetric Water Content

LIST OF PUBLICATIONS

1. Arivalagan, J., Rujikiatkamjorn, C., Indraratna, B., and Warwick, A. (2021). 'The Role of Geosynthetics in Reducing the Fluidisation Potential of Soft Subgrade under Cyclic Loading', Geotextiles and Geomembranes, vol. 49, no. 5, pp. 1324-38. https://doi.org/10.1016/j.geotexmem.2021.05.004.
2. Arivalagan, J., Rujikiatkamjorn, C., Indraratna, B., and Warwick, A. (2022). 'Effectiveness of a Geocomposite-PVD System in Preventing Subgrade Instability and Fluidisation under Cyclic Loading', Geotextiles and Geomembranes, vol. 50, no. 4, pp. 607-617. https://doi.org/10.1016/j.geotexmem.2022.03.001.
3. Indraratna, B., Singh, M., Nguyen, T., Rujikiatkamjorn, C., Malisetty, R. S., Arivalagan, J., Nair, L (2021). 'Internal Instability and Fluidisation of Subgrade Soil under Cyclic Loading', Indian Geotechnical Journal. https://doi.org/10.1007/s40098-022-00616-0.
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5. Arivalagan, J., Rujikiatkamjorn, C., Indraratna, B., and Warwick, A. (2023). 'Cause-and-Effect of Subsoil Fluidization and Preventive Measures by Geosynthetic Drainage' 14th Australia and Newzealand Conference on Geomechanics (under preparation).
6. Arivalagan, J., Rujikiatkamjorn, C., Indraratna, B., and Warwick, A. (2022) 'Effectiveness of geosynthetics in preventing subgrade instability and fluidization under heavy haul loading', Australian Geomechanics Journal. (Under preparation).

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ABSTRACT

In recent times the demand for railway transportation has increased rapidly all over the world because a sustainable mode of transportation is needed to convey passengers and other commodities. However, subgrade soil with low bearing capacity is susceptible to instability under unfavourable drainage conditions. Subgrade soils with low/medium plasticity characteristics that undergo high cyclic stress levels are prone to fluidisation due to the rapid increase in excess pore water pressure (EPWP). Subsequently, subgrade can become unstable which leads to fines being pumped into the ballast/subballast layer (mud pumping). Excessive fine content, EPWPs, applied cyclic stress and frequency are the primary factors that induce particle migration and associated mud pumping. However, the actual mechanisms and cost-effective solutions to prevent subgrade fluidisation were not thoroughly understood due to its complexity and limitations.

In this study, a series of laboratory experiments were carried out to examine the following aspects of mud pumping: (1) the occurrence of subgrade fluidisation by simulating various drainage conditions, (2) the role geotextiles play in stabilising subgrade/ballast interface, and (3) the effectiveness of a prefabricated vertical drain (PVD) and geocomposite system in reducing the fluidisation potential using dynamic filtration apparatus (DFA). Soil specimens were tested at loading frequencies ranging from 1.0 to 5.0 Hz and cyclic deviator stresses from 40 to 70 kPa, simulates a maximum axle load of 35 tonnes. The axial strain (ε_a), EPWPs, and time-dependent excess pore pressure gradient (EPPG) that developed under undrained (impermeable) and free drained (no capping) conditions were used to define the failure criteria. The results showed that geocomposite with an effective filter membrane could prevent the migration of particles under typical train loading (25 tonnes). However, when the cyclic deviatoric stress increased (up to 35-40 tonnes of axle loading), the ability of geocomposites to alleviate the EPWP diminished.

The effectiveness of PVDs was also assessed under various loading conditions. The combined PVD-geocomposite system could reduce the accumulation of EPWPs and continuously dissipate them as the number of cycles increases, thereby providing a viable solution for mitigating the effects of subgrade fluidisation. Design guides were introduced with the field applications at Chullora, NSW. Finally, a numerical study was carried out to evaluate the use of geosynthetics under typical rail track conditions. The predictions revealed the efficiency of geosynthetics at regulating and dissipating the generation of EPWPs under train loading.

Keywords: Subgrade fluidisation; Mud pumping; Geosynthetics; Excess pore water pressure