

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

by Joseph Arivalagan

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the degree of

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under the supervision of Professor Cholachat
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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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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 – Reference 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_{vT} - 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
- CSR_c - 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

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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).
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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