Integrated Ballast-Formation-Track Design and Analysis including the Implications of Ballast Fouling and High Impact Loads: 1st Annual Report

There has been an ever increasing demand for greater reliability of track for heavier and faster trains due to advent in technologies and competition among other modes of transport. Ballasted rail tracks are preferred due to economy, good drainage and ease of maintenance. However, the fouling of ballast by intrusion of fines deteriorates track performance and eventually demands cleaning. Coal spilling from coal wagons, fine particles resulting from particle breakage and soft subgrade clay pumping are the major impurities which infiltrate into the ballast. As a result, the void ratio of the ballast decreases which in turn decreases the permeability and increases ballast deformation. Thus, the drainage conditions and compressibility of the ballast layer become serious concerns leading to unfavourable track conditions and high maintenance costs.

High cyclic loads from moving trains and high impact loads due to wheel and rail imperfections (e.g. wheel flat, turnouts, crossings and insulated joints) contribute to degradation of ballast to a significant extent. In order to design a more efficient track structure and minimise the cost of maintenance, ballast degradation and plastic track deformation due to the effects of fouling and impact loadings must be examined and studied in depth. This project is aimed at providing an integrated ballast formation-track design and analysis including the implications of ballast fouling and high impact loads. The research contributions during the first year are outlined below.

Permeability and drainage criteria: A new parameter *Void Contaminant Index* is proposed to accurately measure the fouling of ballast due to coal fines. A series of large-scale constant head permeability tests (AS: 1289.6.7.3) for different percentage of coal dust have been conducted to investigate the effect of fouling on the drainage capacity of ballast. Permeability and drainage characteristics are assessed for the case of coal fouling based on VCI. The validity of this new parameter is assessed over wide range of fouling percentages in the ballast. The results of large scale permeability tests would be much useful to industry partners as it will help to identify the critical amount of coal fouling which affect the drainage of the rail track significantly in terms of 'Void Contaminant Index' and will thus help to adjust the proper maintenance cycle for cleaning and replacement of fouled ballast. It is found that the hydraulic conductivity of ballast is reduced significantly when mixed with pulverised coal. A small increase in VCI leads to a significant decrease in the hydraulic conductivity of the ballast layer. Beyond VCI of 75%, the hydraulic conductivity of fouled ballast converges to that of coal fines itself. When VCI exceeds about 67%, the drainage condition can be regraded as *very poor* thus requiring urgent track maintenance.

Effect of impact loading on ballast degradation: Occasional high Impact loads are generated during dynamic wheel-rail interaction due to presence of various types of wheel/rail irregularity and discontinuity. Such impact loads are relatively large in magnitude and transient in nature. Several dynamic models are present in the literature to represent the vehicle-track system and their dynamic interaction. However, requirement of an efficient dynamic vehicle-track interaction model is imperative considering the track bed non-linearity and substructure property for proper prediction of track response. An analysis using DTRACK software (dynamic wheel-rail interaction model) has been conducted to assess the impact load magnitudes for different wheel flat configurations. It is found that the ballast pressure increases with the 'flat length' and the corresponding increment is more for a higher flat depth values whereas, wheel-rail contact force decrease with increase in the

flat length. A coupled dynamic analysis of ballasted track structure has been adopted to study the response of ballast layer under such repetitive impact loading at crossing. A discretely supported track section at a crossing is considered, and half of the track bed is modeled considering symmetry. The track-ballast-subgrade system is
modeled by a three degrees of freedom based mass-spring-dashpot system considering a linear viscoelastic response of the substructure layers. Newmark's Average Acceleration method was applied to solve the dynamic equilibrium equation in time domain. MATLAB coding has been employed to get the displacement and acceleration of ballast layer under a square pulse loading phase for representing the impact load at crossing. The results highlight the significance of impact loads on the performance of rail track.

Constitutive model for fouled ballast: A constitutive model is being developed to capture the effect of fouling on the performance of the ballast. The original elasto-plastic stress-strain constitutive model developed by Indraratna and Salim (2004; 2005) including particle breakage has been extended to consider the effect of fouling on the ballast. New intergranular state parameters are defined for more general case of ballast fines (due to ballast breakage) and coal/ clay fines intruded in the ballast. The dilatancy term dependent on confining pressure and particle breakage as proposed in the above model has been now been modified to capture state dependent dilatancy in this model to incorporate effect of density and percentage of fines. Model solutions are compared with the results of large scale undrained triaxial tests with monotonic loading.

Smart tool for track design and maintenance: The development of the smart tool for track design and maintenance is continued under this project following the work done under former CRC project 139. Various empirical approaches to determine the dynamic loads are incorporated in this smart tool. Methodologies to compute the ballast-sleeper contact stresses, rail seat load and subgrade pressure variation along the depth are now included in the smart tool. The incorporation of ballast and sub-ballast separately in the smart tool would provide cost-effective design solution. The cyclic nature of train wheel loads would be incorporated in the smart tool.

Field data Analysis and Interpretations: Field data analysis and interpretation of the data is carried out to evaluate the performance of the instrumented section of track at Bulli on the South Coast of NSW in relation with research findings at University of Wollongong. Several published results in the literature using analytical models such as MULTA, PSA, ILLI-TRACK, GEOTRACK and KENTRACK and also field trials conducted at Transportation Technology Centre Inc., Pueblo are used for the comparison with the observed in-situ stresses and strains in the ballasted track at Bulli. Results of this field trial demonstrate the potential benefits of using geocomposite in track to reduce vertical and lateral deformations. The geocomposite reduces the lateral strains of fresh ballast significantly, thus minimising the lateral spread of ballast, thereby eliminating the need for additional layers of crib and shoulder ballast during maintenance. Also, recycled ballast when used with a geocomposite layer is found to perform as well as fresh ballast without a geocomposite, with obvious implication on reduced maintenance costs. Results also show that the inclusion of a geosynthetic layer at ballast-capping interface may also serve as an alternative method of increasing internal confining pressure. The measurement of in-situ stresses indicate that vertical maximum cyclic stress decreases significantly with the increase in depth while, the horizontal maximum cyclic stress decreases only marginally with depth. Therefore, the need for increasing the confining stress in track (e.g. adding geosynthetic layer within the ballast layer itself) is further justified to improve track stability. Another important finding of this study is that wheel imperfections such as wheel-flat can increase the vertical maximum cyclic stress significantly, causing further ballast degradation.

Site visits: CRC research team visited few sites for assessing the real field track conditions due to fouling and for obtaining coal and clay fouled ballast samples. The site photographs included in the appendix of this report profoundly reflect the importance of this study.