


BALLAST RAILROAD DESIGN

SMART-UOW Approach

Buddhima Indraratna
Trung Ngo

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A BALKEMA BOOK

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Buddhima Indraratna

Centre for Geomechanics and Railway Engineering,
University of Wollongong, Australia

Trung Ngo

Centre for Geomechanics and Railway Engineering,
University of Wollongong, Australia

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Preface

Railway track systems are constructed to provide a smooth and safe transport mode for passengers or freight trains. They are designed to sustain the stresses imposed by lateral, longitudinal and vertical loads acting on the track structure. A ballasted railway track system comprises several components, among which steel rails, rail fasteners, timber, steel or concrete sleepers, granular ballast, sub-ballast and subgrade materials are the main constituents. The recent increases in axle loads, speed and traffic volume, along with the need to improve passenger comfort and reduce track life cycle costs, have created a need for track design optimisation. Furthermore, complementary decision support systems require a more precise analytical and mechanistic approach to meet the design needs of modern railway track systems. These aspects highlight the necessity of a thorough review and revision of the current railway track design.

Given the lack of capacity of current ballasted tracks in many parts of Australia to support increasingly heavier and faster trains, the development of innovative and sustainable ballasted tracks is crucial for transport infrastructure. Ballast degradation and infiltration of fine particles such as coal along the heavy haul corridors and soft subgrade soils contaminating the overlying ballast decrease the porosity of the ballast layer and impede track drainage. This leads to excessive track settlements and instability, as well as increased maintenance costs. To mitigate these problems, the utilisation of geosynthetics (e.g. polymer geogrids, geocomposite, geocells) and recycled rubber mats has been investigated by the authors.

The tangible outcomes of this research study has made a considerable impact on industry in view of forcing design modifications and provision of new technical standards for Australian railways. Already, a considerable portion of the R&D work in this area of research is captured in our in-house computer software (SMART – supplementary methods of analysis for railway track), which can accommodate a variety of problematic ground conditions in Australia in user-friendly modules that enable best track management practices.

This book presents a comprehensive procedure of ballasted track design based on a rational approach that combines extensive laboratory testing, mathematical and computational modelling and field measurements carried out over the past two decades. The Ballast Railroad Design: SMART-UOW approach can be regarded as a useful guide to assist the practitioner, rather than a complete design tool to replace existing rational design approaches. Practising engineers can refer to this book for designing new tracks as well as to remediate existing ballasted tracks with subgrade deformation problems because it provides a systematic approach and greater flexibility in track design. This book can also be used as a useful resource by postgraduate students and as a teaching tool by academics in track design and maintenance.

Buddhima Indraratna
Trung Ngo

Foreword

Studies on ballasted rail tracks have been conducted at the University of Wollongong for more than two decades, and these research outcomes have significantly influenced the way that rail tracks can be modernised through innovative design. Imparting that knowledge to today's rail practitioners, especially those in heavy haul operations, is the objective of Ballast Railroad Design: SMART-UOW approach. This book complements the software SMART (*s*upplementary *m*ethods of *a*nalysis for *r*ailway *t*rack) currently managed by the University of Wollongong together with the Australasian Centre for Rail Innovation (ACRI).

This book deals with both theoretical and practical issues directly related to ballasted tracks, considering a series of options from the selection of mechanical and geotechnical parameters to advanced design examples, capturing the influence of various factors such as particle breakage, ballast fouling, track confining pressure and the application of geosynthetics. The technical content also assists in track maintenance incorporating subgrade deformation and stability considerations, supplemented by case studies and large-scale simulations. Importantly, complex technical content is presented for practitioners in a clear and concise manner, working through examples based on real world situations.

With significantly increased axle loads and speeds of freight trains supporting the mining and agriculture industries in many nations, including Australia, design and construction requirements, and longevity and performance expectations, have become increasingly strategic and challenging than the traditional heavy haul tracks of the past. This is a timely book presenting considerations for contemporary track design and current state-of-the-art practice in ballast railroads. It has been informed through collaborative research with industry, incorporating sophisticated laboratory tests, computational modelling and field studies to advance the design of ballasted tracks.

ACRI congratulates the University of Wollongong on this enhancement to SMART and associated railroad design and analysis and the contribution it will make to the rail industry through informing engineering solutions and advancing industry training.

Andrew Meier,
CEO, Australasian Centre for Rail Innovation

About the authors

Distinguished Professor Buddhima Indraratna (FTSE, FIEAust, FASCE, FGS, FAusIMM) is a civil engineering graduate from Imperial College, London, and obtained his PhD from the University of Alberta in 1987. He worked in industry in several countries before becoming an academic and has been a United Nations Expert and Foreign Advisor to numerous overseas projects. Professor Indraratna's pioneering contributions to railway geotechnology and various aspects of geotechnical engineering have been acknowledged through numerous national and international awards, including the 1st Ralph Proctor Lecture and 4th Louis Menard Lecture of the International Society of Soil Mechanics and Geotechnical Engineering, ISSMGE; the 2015 Thomas Telford Premium Award (ICE, UK); the 2009 EH Davis Memorial Lecture of Australian Geomechanics Society; and the 2014 CS Desai Medal for his substantial and sustained contributions to Transport Geotechnics and Ground Improvement, respectively. Recently, he was the recipient of the 2017 Outstanding Contributions Medal of IACMAG. The New South Wales Minister of Transport awarded Professor Indraratna the 2015 Australasian Railway Society's Outstanding Individual Award at the State Parliament. His pioneering contributions to railway engineering and ground improvement earned him the Fellowship of the Australian Academy of Technological Sciences and Engineering (FTSE) in 2011.

Distinguished Professor Indraratna has made fundamental contributions to transport geotechnology and ground improvement. He has developed unique process simulation equipment for geomaterials and computational methods for predicting the dynamic response of transport infrastructure. His original efforts capture the role of particle breakage in heavy haul rail environments, the only theory to determine the optimum confining pressure for railroad stability, the methods of eliminating impact-based track damage using energy-absorbing recycled materials, innovative computer simulations of vacuum pressure application for stabilising foundations and field-based methods for quantifying soil disturbance. His research has influenced national and international standards and projects in road/rail embankments and port reclamation.

Dr Trung Ngo is an early career researcher with internationally recognised expertise in the field of physical and computational modelling of ballasted rail tracks using Discrete Element Method (DEM) and Finite Element Method (FEM). After graduating from the Ho Chi Minh city University of Technology, Viet Nam, he obtained a master's and a PhD from the University of Wollongong, Australia, under the supervision of Distinguished Professor Indraratna. In 2013, Dr Ngo's doctoral research was acknowledged by Railway Technical Society of Australasia (RTSA) and he was honoured by RTSA Postgraduate Thesis Award, which is awarded once every three years, recognising "contributions to rail industry in transferring the results of advanced computational, theoretical, and laboratory research into professional engineering practices". Dr Trung Ngo is currently a research fellow at the Centre for Geomechanics & Railway Engineering (CGRE), University of Wollongong, working under the Rail Manufacturing CRC project. His research has primarily focused on the area of railway track design, specifically in computational modelling and laboratory testing for ballasted rail tracks.

Acknowledgements

This book was introduced on the basis of knowledge acquired through two decades of laboratory studies, field observations and computational studies on railroad engineering conducted at the Centre for Geomechanics and Railway Engineering (CGRE), University of Wollongong, Australia. It contains research deliverables of numerous sponsored projects completed since the mid-1990s. Many of the concepts and analytical principles incorporated herein have already been described to some extent in the more elaborated textbook *Advanced Rail Geotechnology – Ballasted Track* and in various peer-reviewed research papers published by the first author and his co-workers and research students.

Significant contributions made over the years by Dr Sanjay Nimbalkar, A/Prof Cholachat Rujikiatkamjorn and A/Prof Hadi Khabbaz through their involvement in numerous sponsored ARC and CRC projects are gratefully acknowledged. The authors specifically thank industry colleagues, Tim Neville (ARTC) and, more recently, Dr Richard Kelly (SMEC), for pointing out the imperative need for such a publication to assist modern track designers.

The authors also would like to acknowledge the well-known Australian senior rail practitioners David Christie (formerly at RIC and RailCorp), Mike Martin (formerly at Queensland Rail) and Jatinder Singh (Sydney Trains) for their active collaboration over many years. Particular mentions with gratitude go to Prof ET (Ted) Brown and Prof Harry Poulos, who have supported and inspired the first author over many years, encouraging him to pioneer cutting-edge research in track geotechnology, as this field of research was lacking in Australia. The support received through the ARC Centre of Excellence for Geotechnical Science and Engineering (CGSE) together with three consecutive rail-based Cooperative Research Centres (CRC) during the past decade are gratefully acknowledged.

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A number of important research projects on ballasted rail tracks and geosynthetics have been supported in the past and are currently supported by the Australian Research Council (ARC) through its Discovery and Linkage programs. Keen collaboration with industry partners has facilitated the application of theory into practice. In this respect, the authors greatly appreciate the financial support from the Rail Manufacturing Cooperative Research Centre (funded jointly by participating rail organisations and the Australian federal government's Business Cooperative Research Centres Program). The authors also appreciate the Australasian Centre for Rail Innovation (ACRI), Tyre Stewardship Australia (TSA), Global Synthetics Pty Ltd, Foundation Specialists Group, Sydney Trains and ARTC, among others.

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Finally, the authors also acknowledge the efforts of Dr Udeni Nawagamuwa, Mrs Manori Indraratna and Mr Bill Clayton for their assistance during copy editing and proofreading of the contents.

Chapter 1

Introduction

1.1 General background

Rail networks form an important part of the transport system in Australia and many other countries in the world. Railways play a vital role in its economy by transporting freight and bulk commodities between major cities and ports and by carrying passengers, particularly in urban areas. The Australian rail has carried around one-third of all domestic freight over the past 25 years, and millions of passengers travel in trains each year. For instance, the longest and heaviest train in Western Australia has had a gross weight of nearly 100,000 tonnes and a length exceeding 7 km, with as many as 682 wagons hauled by eight locomotives (Railway Gazette 2001). The need to maintain a competitive edge over other means of transportation has increased the pressure on the railway industry to improve its efficiency and decrease maintenance and infrastructure costs (Indraratna *et al*. 2011a). With ballasted railway tracks, the cost of substructure maintenance can be significantly reduced with a better understanding of the physical and mechanical characteristics of the rail substructure and the ballast layer in particular.

In a ballasted rail track, a large portion of the track maintenance budget is spent on ballast-related problems (Indraratna *et al*. 2011b). Although ballast usually consists of hard and strong angular particles derived from high strength un-weathered rocks, it also undergoes gradual and continuing degradation under cyclic rail loadings (Indraratna *et al*. 2011a; Selig and Waters 1994). The sharp edges and corners are broken due to high stress concentrations at the contact points between adjacent particles. The reduction in angularity decreases its angle of internal friction (i.e. shear strength), which in turn increases plastic settlement of the track.

In low-lying coastal areas where the subgrade soils are generally saturated, the fines (clays and silt-size particles) can be pumped up into the ballast layer as slurry under cyclic rail loading, if a proper subbase or filter layer is absent (Raut 2006; Selig and Waters 1994). The pumping of subgrade clay is a major cause of ballast fouling. Fine particles from clay pumping or ballast degradation form a thin layer surrounding the larger grains that increases compressibility, fills the void spaces between larger aggregates, and reduces the drainage characteristics of the ballast bed (Indraratna *et al*. 2014). The fouling of ballast usually increases track settlement and may cause differential track settlement. Where there is saturation and poor drainage, any contamination of ballast may also cause localised undrained failure. In severe cases, fouled ballast needs to be cleaned or replaced to keep the track up to its desired stiffness (resiliency), bearing capacity, alignment and level of safety (Indraratna *et al*. 2013a; Tennakoon *et al*. 2012).