

RAILWAY ENGINEERING AND GEOTECHNICAL ENGINEERING ARE THEY MARRIED YET?

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ABSTRACT

Challenges for Geotechnical Engineering in Railways and the gap between research work and the needs and expectations of Rail Operators

1 INTRODUCTION

I need to emphasise that this paper will have little if any technical content – it is an opinion and more a philosophical discussion and I hope that it will encourage further discussion.

The suggestion behind this paper was to address the Challenges for Geotechnical Engineering in Railways and the gap between research in Geotechnical Engineering in railways and the needs of the operators. Let me first explain why I put this title to the paper.

For Geotechnical Engineering the challenge is to partner with Railway Engineering in both track substructure design and management and remediation of geotechnical failures, not just for the advancement of Geotechnical Engineering, but for the Rail Industry. What is the relationship between Railway Engineering and Geotechnical Engineering? - Is it a mutually beneficial one? Is the relationship one of equality or is one subservient to the other? Do they share things in common and are they able to communicate meaningfully? Are they already inextricably entwined, or are the two disciplines more useful to each other when they are independent? Can you marry the two disciplines or are they too different?

While there are some critical areas common to Railway Engineering and Geotechnical Engineering, Railway Engineering includes almost all the schools of engineering, Mechanical, Electrical, Civil, Surveying, Industrial, Transport, Structural, and more. Geotechnical Engineering would appear to be having a minor role in this relationship.

Railway Engineering began to develop even before the invention of the steam engine, with horse drawn wagons on rails as questions arose about wheel and wagon design, rail design and track construction and support for the rail. Geotechnical engineering on the other hand has been recognised as a separate discipline in relatively recent times and it has taken a long time for the rail industry to acknowledge the significant contribution geotechnical engineering makes to rail operations. For example, in NSW, it took the La Nina of 1989 to 1990, when there were landslides and embankment failures along the corridor on both the north and south coast, to force the State Rail Authority of NSW to acknowledge that it needed to commit significantly more resources to Geotechnical Engineering.

There have been significant advances in the discipline of geotechnical engineering since the discipline was recognised, both within and without the railway industry. Over the last 30 years a huge amount of geotechnical research directly related to the rail industry has been conducted in the US, Canada Europe and the UK. More recently Australia has become a leader in railway track research including ballast and formation design with the work of the Cooperative Research Centre (CRC) in Rail and CRC for Rail Innovation, conducted out of the University of Wollongong (UoW). How much of this research has been adopted in the rail industry and how is it regarded by rail practitioners?

This now leads us back to the suggested paper topic.

- What are the Challenges for Geotechnical Engineering in Railways?
 - What is its role in the rail industry.
 - What constraints exist?
- Is the research in geotechnical engineering useful to the Rail Industry?
 - Does it address the issues that the industry struggles with?
 - Does it assist the industry with its needs and expectations?
 - Is there a gap between this research and the needs and expectations of the Rail Operators?
 - If there is a gap, how is it to be breached?

2 THE RAILWAY ENVIRONMENT

To address these questions and to appreciate the role of geotechnical engineering in railways and the relationship between geotechnical engineering and railway engineering it is necessary firstly to be familiar with the railway environment, the history and traditional practises. This environment has changed dramatically in recent years and is still changing.

In Australia, until the last 20 years, railways were described as “vertically integrated” and state or privately owned and operated. These railways were owned by state governments, the commonwealth government, a number of coal mining, electricity generating and sugar milling operations. The owner had their own in-house expertise and systems for the building and maintenance of the infrastructure as well as for the operation of the rail services. Both rail infrastructure and rail services were therefore driven by customer demand.¹ The railways controlled the rail operations on their infrastructure and limited its use to their own rolling stock.

With the introduction of a national competition policy in 1995, providing third party access to infrastructure services,² owners of infrastructure were required to provide (sell) train passages on their network to their competitors.

Subsequently the rail industry in Australia has been changed to organisations that are “above rail” operations or “below rail” infrastructure with the changes taking place as follows:

- In 1998 the Commonwealth Government formed the Australian Rail Track Corporation (ARTC), to develop a national standard gauge network. ARTC subsequently acquired the standard gauge network from Broken Hill NSW to Kalgoorlie in Western Australia and a lease to manage the Victorian interstate standard gauge network.³
- In NSW in 2002 the freight side of the operations, FreightCorp, was sold to Pacific National
- In 2004, ARTC took up a 60 year lease on the NSW interstate rail network including the lucrative coal lines in the Hunter Valley and contracted to maintain the lesser trafficked Country Regional Network for the NSW Government.
- In 2009, ARTC entered into a 50 year lease of Victoria’s mainline standard gauge network.
- Numerous other companies were formed as rail operators
- Recently the Queensland Government has sold its Freight Division and QR National has been formed

No longer is it possible to assume previously held beliefs of continuity of knowledge or expectations exist in-house from the ground to the train. Owners and lease holders are less likely to have their own in-house expertise, especially in specialties such as Geotechnical Engineering. It is more likely that such expertise will be out sourced to external consultancies or contractors. The challenge for Geotechnical Engineering consultants is to learn where such knowledge can be found and to develop their own corporate memory.

As a consequence of the changes to the Rail Industry after the implementation of the National Competition Policy, the industry is now fragmented with a variety of organisations. The industry now includes the following, each with their own set of challenges and expectations:

- **Owners or lease holders**, most notably ARTC, Transport NSW
- **operators**, there are now at least 18 different freight and passenger rail operators in Australia
- **owner/operators**, including RailCorp, QR National, Queensland Rail, several mining companies
- **Infrastructure maintainers**, Including John Holland Rail, AbiGroup Rail, Downer Australia and other contractors

2.1 OPERATIONS OR “ABOVE RAIL”

“Above rail” or rail operation is principally the business transporting freight and passengers. The prime interest of Operators is to meet the needs and expectations of their customers. Operators own the locomotives and/or rolling stock, and are responsible for maintaining, upgrading their rolling stock. Their interest is in advances in traction capacity (locomotives), rolling stock design, and in improvements in speed and reliability.

For rail operators the challenges vary from customer to customer with a constant “battle” of competition with road transport.

Their chief challenges are related to customer expectations and demands which include:

¹ (Bugler P. Rail Express June 2010)

² <http://ncp.ncc.gov.au/pages/about>

³ <http://www.artc.com.au/Content.aspx?p=32>

- safety,
- Reliability
- Reducing Cost and improving efficiency
- Reducing travel times: increased speeds, reducing delays
- Increasing capacity: longer trains, increased axle loads

2.2 INFRASTRUCTURE OR “BELOW RAIL”

Infrastructure owners or leaseholders have the responsibility of “below rail”: maintaining, upgrading, and replacing infrastructure and their prime role is to provide train paths for their customers, the Operators. Their source of income is from the provision of train paths, meeting the expectations of the operators and satisfying industry standards.

As described in their web site⁴ ARTC is responsible for:

- Selling access to train operators
- The development of new business
- Capital investment in the corridors
- Management of the Network
- The management of infrastructure maintenance

Train control is a major challenge, to develop new and more efficient methods of train control that maintains high levels of safety. However infrastructure maintenance is a major challenge for owners and maintainers, especially with old infrastructure, both in engineering innovation to solve problems and meeting the demands of the industry at a manageable cost with limited track access.

Therefore the challenges for infrastructure owners and maintainers is in meeting customers’ expectations and is aptly described by ARTC CEO, John Fullerton “Our feedback from operators and directly from customers is that it is all about three things “reliability, reliability, reliability”⁵. This relates directly to the condition of the infrastructure and maintenance cost is a large liability.

The success of their enterprise is therefore meeting these expectations cost effectively.

3 GEOTECHNICAL ENGINEERING AND RAILWAYS

Geotechnical Engineers therefore need to recognise that they are working within the framework of these challenges facing the railway industry. The challenges facing the operators and owners are passed down to the engineers who deliver the services.

Where does Geotechnical Engineering fit in with Railways? It is clear that for the most part geotechnical engineers will be providing services to Infrastructure Owners or lease holders whose income is determined by the operators that are attracted to the network and the train passages generated. Due to the competitive nature of the industry today, there is no longer a guarantee, as used to be the case with Government owned networks, that issues will be addressed at any cost. Infrastructure owners of freight networks are now required to balance the income from train paths with the cost of providing that access. For Government owned passenger networks there are issues of safety and reliability to be achieved at lower costs against much limited track access.

However while Geotechnical Engineering has an apparently small role to play in Railways, the role is crucial to safety, reliability and performance, yet facing the same challenge on cost effectiveness. Geotechnical Engineering is responsible for the supremely important characteristic of a strong foundation and a safe rail corridor.

There is an overall challenge for Geotechnical Engineering to provide advice that will fit within the limitations set by Infrastructure Owners without comprising the integrity of the advice.

3.1 THE RAIL CORRIDOR

In the rail corridor the issues affecting safety including problems of unstable embankments and slopes, rock falls and landslides.

These issues are not new to railways or railway engineers; they are problems that have been faced since the first railway. It is necessary for geotechnical engineers today to appreciate how these problems were traditionally handled.

⁴ <http://www.artc.com.au/Content.aspx?p=14>

⁵ Fullerton J, Rail Express November 2011.

Historically the pressure from the operations side of the rail industry on the infrastructure was to keep the trains running at all costs. This resulted in pressure on remedial works to be restoring track as soon as possible, with temporary repairs. These remedial works were often temporary for some time and sometimes left in place permanently to be incorporated into the substructure. The track over many an embankment failure was temporarily supported on “pig stys” which eventually became part of the embankment fills, See Figure 1a. To the other extreme, massive engineering structures were built to support the track in areas of repeated failure. See Figure 1b.

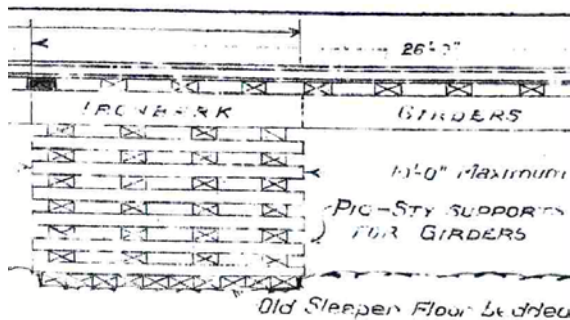


Figure 1a, Sleeper Pig-Stys to support collapsed track.

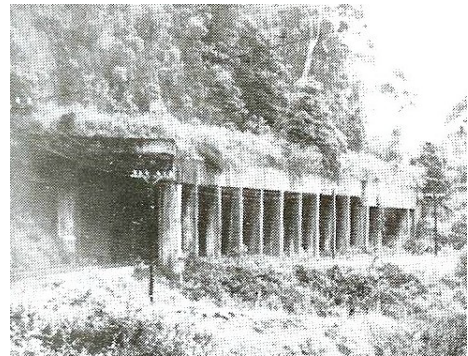


Figure 1b, Rock Fall Shelter over the track.

Some of these structures managed to address the underlying problem, others did not.

Traditionally remedial methods of slope stability control relied heavily on man power as the cost was low. Intricate structures could be built in areas of restricted access by man handling equipment and materials through difficult terrain, such as building brick columns under rock overhangs high above the track. Today the cost of labour is prohibitive and solutions often required the building of costly access roads for heavy machinery.

Challenges for Geotechnical Engineering in Railways include several areas: Problem Solving, Site investigation, Risk assessment, and Analysis.

3.1.1 Problem Solving

Geotechnical engineers are often asked to solve problems after the owner or maintainer has tried several solutions without success or has inherited a problem from previous owners/maintainers and have no maintenance history. Very often the owner may nominate a specific solution and the challenge for the geotechnical engineer is to verify if the solution is feasible and appropriate.

The challenges as always are to:

- Firstly define the problem. Is the problem, operational, structural, foundation and support, procedural, or systematic? Many times a problem is not as first reported and not even be a geotechnical one. Reviewing the site history is an important step. Tracking down old railway workers is often helpful.
- Then, identify the failure mechanisms. Is it related to previous repairs?
- Identify the contributing factors and the cause,
- Develop solutions to address the cause/s identified. Often the options are much clearer if this procedure is followed

Unless this procedure is followed there is likelihood of developing a solution that does not address the cause and in some cases becomes a contributing factor for further problems. Also following this procedure it is possible to justify an expensive solution when that is the only feasible one.

3.1.2 Site Investigation

In the railway environment investigating geotechnical problems involves significant challenges; limited access, limited space, limited time, issues of safety around operating rail lines.

Conducting geotechnical investigations in such an environment it is difficult to get enough information on the substrata. Rather than making interpretations with the limited information from subsurface exploration alone, it is important to use other sources of information; topography, geomorphology, historic records and feedback from “old railway workers”.

3.1.3 Risk assessment

Another challenge for geotechnical engineering is to be able to assess risk, both qualitative and quantitatively, where appropriate. Determining the likelihood of failure of a particular problem is simplified if the above problem solving sequence is followed.

Solutions need to be developed within a risk-based framework of acceptable risk.

Can the rail industry afford solutions that eliminate risk? It is not appropriate nor economically possible to develop solutions that eliminate risk at any cost. Solutions need to be cost effective and appropriate. There have been many an accusation that geotechnical engineers produce “gold plated” solutions.

A thorough analysis of the likelihood of a failure event along with a realistic evaluation of the consequences will provide a platform for the assessment of measures to reduce the risk.

3.1.4 Analysis

Finally with the increasing sophistication of mathematical modelling there is a temptation to believe the “model”, in spite of the evidence. The analysis is only a model and not a perfect copy of reality. It is always necessary to do a sanity check. For example, stability analyses may demonstrate that the majority of rail embankments that were built 100 years ago are unstable or marginally unstable. Yet they have generally stood the test of time, which is notable, especially considering the generally poor construction practices adopted at the time. Failures that have occurred can most often be contributed to specific and local factors. Therefore to advise that a particular location is “unsafe” based on the analysis alone is unwise.

The challenge is to use analysis wisely, with frequent references to the actual performance of the structure and adjacent structures. It is important to be aware of the underlying assumptions. Relying totally on analysis can lead to expensive unnecessary solutions and sometimes cause significant unnecessary disruption to services with considerable cost penalties.

3.2 TRACK SUBSTRUCTURE

Track related issues are similar. The track geometry is a key issue for train operations – it contributes in a significant way to the speed, reliability and safety of the track and the uniformity of the track geometry is governed by the adequacy of the track substructure.

The design of the track substructure has been the subject of much effort since the beginning of rail transport – before the invention of the steam engine. But now with greater and greater expectation from rail transport, in terms of speed and load capacity, the substructure is under greater and greater scrutiny. In NSW many sections of the network are still supported on substructure built more than 100 years ago. Embankments were often end tipped in layers several feet thick and compacted only by the passage of the horses and drays used to cart the fill. Many tracks were originally laid in ash material until the use of igneous rock as ballast became more readily available. Emergency repairs of the track after embankment subsidence problems relied on readily available fill, which again was often ash material from the steam locomotives boilers.

Improvements to rail design, sleeper design, and fastenings from the dog spike to sleeper plates to resilient fastenings have improved the performance of the track immensely; however, these superstructure improvements are often superficial with the old substructure capacity determining the long term performance of the track geometry.

Traditional railway solutions have often left a legacy for future remedial work and it is important to verify whether these activities took place at any particular location.

Mud jacking, where cement grout was pumped into the track substructure to fill depressions under the track, provided only a temporary fix and became part of the problem

Interspersed concrete and timber sleepers - used to make up for the poor quality of the timber sleepers can create an uneven track response, particularly where inconsistent tie patterns are used

Re-sleepering with concrete sleepers without addressing the substructure was intended to improve the strength of the track at reduced cost, however the more rigid concrete sleeper and reduced ballast depth cause rapid failure of the substandard substructure. See photo.

Sledding was used on country lines to lift the track above the foul ballast, break up the sleeper bays and turn the old ballast into “sub ballast”. This actually was a cost effective solution to upgrading the old substructure



Timber supports were used under the sleeper in areas of very low strength and were often left in place to rot and create future problems.

Designing new track substructure is one challenge; however how to address the deficiency of the existing substructure is another. This is the challenge facing the infrastructure owner and the one directed to the geotechnical engineer to solve.

As with the rail corridor the Geotechnical Engineer will be asked to: Solve track substructure problems, conduct Site Investigations for the design of track substructure, and Design track substructure for new or reconstructed track. The same process outlined for solving problems above is also appropriate for track substructure.

3.2.1 Site investigation

The challenge for the geotechnical engineer when investigating track related problems is more accentuated for track work with: limited and difficult access due to the rails and sleepers, very limited space, time limited to periods of track possession, and issues of safety around operating rail lines.

The challenge is also to develop methods of investigation that provide both the details of the substructure and its performance history. A bore hole tells very little compared to a test pit across the track which will also reveal the behaviour of the subgrade (see photo). And yet a test pit has its own limitations for conducting in-situ testing, such as SPT and shear vane tests.



Track substructure investigations which focus only on the area below the track at the problem site can lead to limited results. Looking beyond the problem location for other contributing factors, such as the type of the material from adjacent cuttings may provide a clue as to the origin of the fill material, and local drainage patterns will assist also, etc.

It is important to research into the history of the track substructure before attempting to start interpretation of the information from the subsurface investigation and before rushing in with solutions. As listed above, there are those and other traditional activities that may have been conducted at the site and the information from the investigation needs to include that history.

3.2.2 Analysis and Design

The methods of analysis of the stress distribution to the subgrade and substructure design used by many railroad companies and organisations have for many years relied on empirical formulae developed in the early 20th Century or on similar in-house empirical methods developed by railroad companies. In more recent times “rule of thumb” methods based on strength properties of the subgrade and imported fill, again empirically based, have been standardised by organisations such as RailCorp and ARTC. Other rail owners such as Queensland Rail have developed design methods that follow similar logic to road pavement design and include load repetition and elastic deformation criteria.

These methods all utilise static loads factored up to allow for the cyclic and dynamic loads that are known to apply for rail track. These methods have appeared to provide satisfactory results, which explain their continued use.

More recently (in the last 20 years) several computer software models to analyse the response of the track superstructure and substructure to rail loading have been developed in the US and Europe. However when these design methods are applied without the benefit of the corporate memory that comes with in-house experience, the track substructure design delivered can sometimes be very excessive. This may explain why these methods are not widely used.

When existing failed track is to be reconstructed during the short periods of time of track possessions, when train operations are suspended, a substructure design which is excessive may not be achievable in the time provided. The challenge for geotechnical engineering is to verify the proposed design against the performance of the existing track in similar situations and to modify the assumptions for the analysis and design to develop a realistic and achievable design.

The Challenge for Geotechnical Engineering is to develop practical substructure analysis and design methods that replicate the actual cyclic and dynamic conditions that apply for rail track. This will become more critical due to the greater demand on rail for heavier loads and higher speeds.

4 RESEARCH IN GEOTECHNICAL ENGINEERING FOR RAILWAYS

The second part of this paper is to look forward at current geotechnical research in Railways.

- Is the research in geotechnical engineering useful to the Rail Industry?
- Does it address the issues that the industry struggles with?
- Does it assist the industry with its needs and expectations?
- Is there a gap between this research and the needs and expectations of the Rail Operators? If there is a gap, how is it to be breached?

Since the inception of the Rail CRC in 1999, there has been significant research in the Rail Industry in Australia. A lot of research has been related to operational issues and wheel to rail interaction; however The University of Wollongong (UoW) has lead the field in Australia research in Geotechnical Engineering for railways.

Nevertheless, this is not new. Research work for rail, including geotechnical, has been conducted for many decades as far back as 1888, with A Zimmerman in Germany developing an analysis of load transfer from rail to through the formation. Further significant work on analysing the load distribution rails to track formation was conducted by A N Talbot in 1918 with “Stresses in Railroad Track” followed by C W Clark in 1957 with “Track Loading Fundamentals”⁶. This work eventually developed into empirical formulae and even today the results of this work is still applied by major rail industry groups.

More recently in the 1970’s, major geotechnical rail research has been conducted in Canada on the specification of rock for use as ballast, and the review of the behaviour of ballast. At present Rail Geotechnology research is being conducted in numerous universities in Europe, the UK and North America.

In Australia since the inception of the Rail CRC, the UoW has advanced the research on ballast and the track substructure to new levels of sophistication. The research is becoming increasingly discretised, with more and more laboratory tests on the separate components and with the focus on more and more accurate Finite Element modelling to reproduce the laboratory tests results.

The focus is also turning to extending the research to High Speed Rail, and to the impacts that has on the substructure and its components, while the likelihood of HSR in Australia becoming a reality soon is very low.

4.1 ADOPTION OF RESEARCH

However, how much of this research is being taken up by the rail industry? The research is detailed and highly sophisticated, but who is using it?

The critical measure of success is whether the research is assisting the maintainers and operators to meet the challenges they face, to develop tools to assist the industry. There is an opinion in the rail industry that it does not require more and more precise tools to describe the substructure. Rail track is very imprecise. Robust “blunt” easily applied solutions are what is needed.⁷

Dale Coleman, Managing Director TTG Transportation Technology, has been quoted in an article about rail innovation: “it strikes me as bizarre that our own government’s spending on R & D is almost totally focussed on academic research and little is done to ensure this can find a way to commercial outcomes”.⁸

For the maintainer, it is necessary to know where to focus the maintenance effort, before the failure occurs, to ensure the network remains reliable. Knowledge of the condition and performance of the substructure will assist in the effective planning of the maintenance cycle. To know where the problems are developing in the network will mean they can be addressed well before they impact on network reliability, and will assist in the economical use of resources. To know why the track of the same quality fails repeatedly, in one area and not in another, under the same loading conditions, would enable the maintainer to plan remedial work ahead of time. Research that predicts the life of the substructure or its separate components is something that can assist the maintainer to maintain the reliability of the track.

4.2 COMMUNICATION

How is the research communicated to those who can benefit from it?

Academic work is often presented in academic journals such as American Society of Civil Engineers (ASCE), the Institute of Civil Engineers (ICE), Geotechnique and the proceedings of academic conventions, but these are not read

⁶ William W Hay, Railroad Engineering 1982

⁷ Personal communication with M Kerr, RailCorp, 9th July 2012

⁸ Jennifer Perry, Rail Express August 2010, “Matching Local Industry with global opportunities”.

by rail practitioners who struggle to solve everyday problems, some of which are only discussed in these academic journals. What is the forum acceptable to the Rail Practitioner?

While the most visible part of the railway is the infrastructure and the track and structures, rail industry journals give a lot of attention to locomotives and rolling stock, rails and fastenings and the “big yellow machines” that are used in maintenance. These journals reveal that the strong focus in Rail Engineering is on advances in the development of the rolling stock and the components of the superstructure. In these journals little attention is given to the substructure.

Is this because the advances in the knowledge of how the track substructure behaves, under increased cyclic and dynamic loading, are presented in another forum and in language not accessible to the rail practitioner?

Owners and maintainers need tools they can use to better manage the track substructure. They need to hear about what is being developed and how it will assist them in language that is meaningful to them. The tools also need to be uncomplicated and accessible otherwise the results of the research will join other advances that remain in Academic Journals and the Rail Industry will continue to use the methods they have found to work!

I suggest that there is a gap between research in Geotechnical Engineering in railways and the needs of the infrastructure owners and maintainers and it is in communication and application. I would suggest that the more and more precise modelling produced by the research and baulked at by rail practitioners is exactly what is necessary to develop the practical tools needed by them. I believe the GAP is communication.

5 CONCLUSION

To answer the initial question in the title: it is clear that Geotechnical Engineering has always had a crucial role within Railways. It is also apparent that there are some significant advances required from both disciplines before a confident relationship will develop.

The challenge for Geotechnical Engineering is to partner with Railway Engineering in both track substructure design and management and remediation of geotechnical failures, not just for the advancement of Geotechnical Engineering, but for the Rail Industry. To stand beside the Rail Industry and share the challenges and limitations of cost imposed on the industry.

The challenge to Geotechnical Engineering is to demonstrate that the results of a more detailed investigation and analysis can be easily applied and be of benefit both in ensuring that the design will be more efficient, addressing the actual problem and that it will improve performance for the life of the infrastructure.

The challenge for Geotechnical Research is to demonstrate that better and more accurate analytical models of the rail substructure are not just for academics and can provide operators with the confidence that the investment in the research will return a design that can guarantee to provide the reliability expected. The research also needs to assist in asset management to assist in the effective planning of the maintenance cycle so that there are “no surprises” and that intervention and maintenance measures can be accurately forecast and planned.

Over and above these challenges there is the need to communicate to the rail practitioners and rail operators the Advances in Geotechnics in language acceptable to them so that these advances can be appreciated and properly considered by those who need to implement them.