

# **RAILWAY ENGINEERING–2003**

## **Abstracts of the Sixth International Conference**

on

### **“Maintenance & Renewal of Permanent Way; Power & Signalling; Structures & Earthworks”**

30<sup>th</sup> April - 1<sup>st</sup> May 2003

Venue:  
The Commonwealth Institute  
London

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**[www.railwayengineering.com](http://www.railwayengineering.com)**

# RAILWAY ENGINEERING–2003

*First published in April 2003*

*by*

**ENGINEERING TECHNICS PRESS**  
*46 Cluny Gardens*  
*Edinburgh EH10 6BN, UK*

*Tel: +44-(0)131-447 0447*

*Fax: +44-(0)131-452 8596*

[www.railwayengineering.com](http://www.railwayengineering.com)

email: [books@ecspublications.com](mailto:books@ecspublications.com)

*ISBN 0-947644-50-4*

*© The Contributors*  
*named in the List of Contents 2003*

*Printed in Scotland*  
*by*  
*Meigle Colour Printers Ltd*  
*Tweedbank Industrial Estate, Galashiels*  
*Tel: +44-(0)1896-753076*

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# RAILWAY ENGINEERING-2003

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# **KEYNOTE PAPERS**



## **THE CONTRIBUTION OF RAIL METALLURGY TO TRACK INTEGRITY**

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**Keywords:** Rail, metallurgy, track, integrity.

The complexity of the track system is widely recognised but more importantly, despite considerable research, the rail-wheel interface and its implications for track and vehicle degradation and maintenance continue to challenge the industry. Reference is often made to “the System’s Solution Approach” for engineering a ‘through-cost’ solution to meet the requirements of the track engineer. However, evaluating proposed solutions in a system’s context is often overlooked in favour of the isolated assessment of an individual parameter affecting system performance. Hence, it is necessary to establish the definition of the track system and the disciplines required to achieve and maintain the desired level of track integrity

A key statement describing the role played by metallurgy in other fields is that over 70% of the steels in use today were invented in the last ten years and yet the vast majority of the track in any country utilises steels that were invented quite some time ago. The metallurgical developments of rail steels have largely been left with the manufacturers in contrast to the earlier practice in the industry of active participation of bodies such as the “Improved Rail Steel Liaison Group” that brought together the permanent way expertise of the industry with the metallurgical knowledge of the rail manufacturers. However, the effective use of any newly developed steel is dependent

on the knowledge of what is required – “you can only provide an answer if you know the question”. This paper addresses many of these issues.

## **REMEDICATION OF RAILWAY EARTHWORKS**

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**Keywords:** Design integration, value engineering, alliancing.

Arup were commissioned by Network Rail to investigate causes of instability of 6 railway earthworks, comprising two cuttings and four embankments located in the Great Western Zone. Once the cause of instability was established, topographic surveys and ground investigations were completed, and remedial solutions designed. The author was part of the geotechnical team responsible for the identification of the causes of failure and subsequent design of remedial measures.

The causes of instability included deep seated instability due to failure of the underlying embankment foundation material, and local instability of ballast at the embankment shoulder caused by raising of track level by routine maintenance of the track over a number of years.

The stabilisation method adopted for each site was dependent largely on the mode of failure, underlying geology and the need to maintain the operation of the railway during implementation of the proposed works. Solutions included bored concrete soldier piles with regrading of embankment slopes and the use of shear trenches, a novel form of embankment stabilisation involving deep counterfort drains.

The paper concentrates on the

geotechnical aspects of the projects, and therefore presents details of three of the six earthworks sites considered. This includes the geometry and geology of the sites, the form of the assumed cause of the instability and details of the proposed remedial works. It also provides a commentary on works implementation through an alliance contractor, and identifies the benefits of this method of design and procurement.

## **QUANTITATIVE RISK ASSESSMENT OF RAILWAY INFRASTRUCTURE**

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**Keywords:** Risk assessment, safety, railways, QRA.

Recent interest in asset management, particularly within the railway industry, and the need to prioritise work within investment programmes, has placed upon engineers an increased need to undertake suitable and sufficient risk assessments. This paper discusses some of the limitations of qualitative risk assessments and presents options for undertaking quantitative risk analysis (QRA), including analysis of relatively large populations of infrastructure assets using risk models. The importance of QRA is discussed, together with benchmarks against which the output should be compared, and comments made on the important role of the engineer in QRA and risk models.

## **INNOVATIVE USE OF FRP TO STRENGTHEN RAILWAY BRIDGES**

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**Keywords:** Bridges, FRP, strengthening.

Network Rail is the successor to Railtrack as the owner of the United Kingdom's (UK) main line railway network. The bridge portfolio associated with its network is large and varied, consisting of about 40,000 bridges, which equates to about 68,000 individual spans. About half of this stock consists of masonry arches, with the balance consisting of about 16,000 metallic structures and 4,000 concrete decks. Of the 40,000 bridges, about 28,000 carry the railway over obstructions such as roads, rivers and valleys and over 6,000 carry public highways over the railway. The balance carry private roads, farm tracks and watercourses over the line.

This paper describes how fibre reinforced polymer composite materials became accepted for use on Network Rail's bridges, the controls that have been put into place to ensure that the introduction of FRPs has been accomplished without compromising safety and the management processes put in place to ensure that strengthened bridges can be kept safely in service.

# FAILURE STATISTICS AND MAINTENANCE ACTIVITIES FOR RAILWAY TURNOUTS IN SWEDEN

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**Keywords:** Turnouts, failure modes, failure statistics, maintenance strategy, railways.

Turnouts are critical subsystems in a railway system. Today there are a large number of problems due to the non-functioning of turnouts, especially during the winter season. The goal of the present study is to investigate whether the information available in different databases is useful for degradation trending and to serve as a base for the improvement of both routines and technical design.

With the information available in databases it has been possible to make a brief analysis of the situation. A preliminary study shows that 10% (250) of the turnouts studied contribute to 21% of all the inspection complaints and to 35% of the reported malfunctions. An extended analysis of these turnouts might give further understanding of factors related to their problems. This paper presents a general discussion on the relationship between inspection results and occurrences of failures.

Some of the major results are:

- Trends of degradation are possible to calculate, but this is not carried out within the current strategy. Data from measurements performed in inspections should be reported and documented before alarm levels are reached.
- Redesign of the switch-blade control sensor, the switch mechanism and the electric heater system seems to be very

urgent and will, when carried out in practice, reduce the number of faults reported.

- Malfunctions in turnouts can be reduced by systematic preventive maintenance and reviewing of current routines.

It is obvious that a strategy for the documentation and follow-up of maintenance activities is lacking and that such a strategy is strongly needed.

Important factors when analysing the statistics of different turnouts are discussed in this paper.

Findings from the study suggest that a well thought-out strategy for data collection and communication should be formulated and implemented to improve the functioning of the turnouts.



# **Theme 1: Railway Track**

## **Day 1:**

### **Influence of Rolling Stock on Rail + Track**



## **SIMULATION OF RAIL WEAR AND ROLLING CONTACT FATIGUE USING THE WHOLE LIFE RAIL MODEL**

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**Keywords:** Rolling contact fatigue (RCF), gauge corner cracking, rail wear.

The Whole Life Rail Model has been developed by AEA Technology Rail and the University of Sheffield as a practical engineers decision support tool to help control rolling contact fatigue (RCF). The model can be used as an 'asset management' tool to assess the likelihood of crack initiation, and to set rail grinding rates and intervals to keep the risk of RCF development under control.

The model consists of a number of 'modules' which evaluate rail wear, crack initiation and different phases of crack growth. The model assembles the modules to determine the interaction between wear and fatigue crack growth and assesses the risk of RCF cracking developing. Each module is under constant development, one aspect of which is the effect of different vehicles on wear and damage of the rail. Vehicle dynamics simulations are used to determine the conditions of the contact patch at the wheel-rail interface, and the contribution to wear and damage at the rail head imposed by each passing vehicle.

This paper describes how the model can be used together with vehicle dynamics simulations to predict, in particular, rail wear and worn rail profiles.

## **DEVELOPING ROLLING CONTACT DEFENCE PLANS FOR INFRASTRUCTURE**

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**Keywords:** Rail, rolling contact fatigue, wheel rail interface, defence plans.

Numerous parallel development and implementation efforts continue to be directed toward solving the problems of rolling contact fatigue (RCF) on the British railway system. These efforts are focused on both sides of the wheel-rail interface. Many of these programmes are dependent on the results of complex research and analytical tasks, and are not quite ready for application in the field. While work continues on the specific areas of investigation and research, the symptoms of RCF continue to occur on the operating railway.

This paper describes a current programme to develop and implement defence plans for treating the symptoms of RCF on the British railway system. The programme targets a prioritised list of actions that are considered to be practical and achievable in service, with the intent that both establishing actions and the prioritisation of those actions must be an iterative approach, refined as knowledge improves.

# **EMBEDDED SLAB TRACK TEST TRACK IN SPAIN: CONSTRUCTION OF A LOW MAINTENANCE CONCRETE SLAB TRACK**

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**Keywords:** Embedded, slab track, Spain.

This Paper describes the installation of the Balfour Beatty Embedded Slab Track (BBEST) system in a section of Test Track constructed for the Spanish high speed railway authority Gestor de Infraestructuras Ferroviarias (GIF).

The Paper highlights the design and construction aspects of the BBEST system that are particularly pertinent to low maintenance track systems.

As background to this work, which was carried out during the first quarter of 2002, the Paper outlines the worldwide experience of Balfour Beatty Rail in the field of Slab Track design, construction and maintenance, much of which has contributed to the reasons for developing the BBEST system.

The Paper gives a brief description of the BBEST system and the methods used for the installation in Spain. It also refers to the testing and monitoring that was carried out on the section of Slab Track, particularly with regard to rail deflections under traffic and the performance of the track in terms of noise and vibration.

The Paper highlights the aspects of design and construction that contribute to a low maintenance trackform and then sets out the proposed future developments of the BBEST system that Balfour Beatty intend to carry out, that will further enhance the

low maintenance characteristics of the system.

# **COMPARISON & ANALYSIS EFFECT OF VIBRATION CONTROL SLEEPER PAD ON GWE\_MOK ELEVATED RAILWAY BRIDGE IN JEOLLA LINE**

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**Keywords:** Vibration control, sleeper, high noise level, vehicle dynamic loads.

Any noise and vibration from railway line is carefully considered most important factor to estimate railway safety and passenger comfort. Even though railway has recognized the very friendly environmental transportation than motors it still has heavy environmental problem such as high noise level and vibration from railway line.

There are few reasons for vibration and noise from railway line. In order to reduce vibration levels, its source and routes must be prevented. The reduction of vehicle dynamic load can be best solution dealing with this matter. Diminution of sleeper spring constant is also considered another solution.

In this paper, the effect of vibration reduction with vibration absorber is investigated on Jeolla line (south-west line of South Korea). The results are compared and estimated based on different measuring factors.

# **Theme 1: Railway Track**

**Day 1:**

**Rail Inspection**



## **DEVELOPMENT OF ULTRASONIC RAILWAY INSPECTION SYSTEMS USING PHASED ARRAY METHODS**

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**Keywords:** NDT, ultrasonic, phased array, railway, inspection, directivity pattern, crack analysis/sizing.

This paper presents the state of the current activities to develop an ultrasonic railway inspection system using phased array methods. The aim is to build up a system, which can perform a crack analysis and sizing. At first a probe, which was designed for the wheel disk and railway inspection, will be presented. The subject area of this paper will be the railway inspection. The probe was designed using a point source synthesis model [Boehm, 2002], which is developed over several years at the laboratory. The model was used to compute the directivity pattern of the probe. A comparison will show the good congruence between the measured and computed directivity pattern of the probe for some different angles of incidence. The soundfield control using the phased array technique allows high detection probability and size estimation of cracks. The evaluation of the results obtained make easier to determine which repairing measures are required and their urgency.

A phased array probe in sequence can replace different conventional probes. That implies a great variability during the inspection. However, the sequential excitation of the probes by a phased array device causes a drop of the examination velocity compared with the currently used systems. The inspection system should be optimized to cope examination velocities of 25-30 km/h. The results obtained with rail specimens at the laboratory are presented in the contribution.

## **EDDY-CURRENT DETECTION OF HEAD CHECKS ON THE GAUGE CORNERS OF RAILS: RECENT RESULTS**

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**Keywords:** Gauge corner cracks, rail, eddy current, NDT.

Deutsche Bahn's track network is subjected to very high levels of operational stress. High train speeds and heavy axle loads are the critical factors affecting the service life of the rails. This places increasing demands on the rail technology used and has tightened the requirements that need to be met by non-destructive material testing techniques. For example, defects occurring at or near the surface of rails can be a major cause of component failure and therefore require a test method that is specially designed to detect rail defects of this type.

A major consideration for safety inspections of the permanent way is the speed with which the rails can be scanned. Today, rail test vehicles are available which enable rail defects to be detected and analysed at speeds of up to 100 km/h.

## **BEHAVIOUR OF SURFACE CRACKS UNDER WHEEL/RAIL CONTACT LOADING**

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**Keywords:** Railhead stresses, rail surface defects, railhead subsurface cracks, crack propagation.

Surface cracks in railhead adversely affect the safety, economy and passenger comfort of the railway operation. Although surface cracks are easily inspected and maintained (usually removed using rail grinding if detected very early), often the associated subsurface cracks - if gone undetected - could lead to catastrophic failure of the rail. Therefore, a closer investigation of the subsurface cracks near the surface defects is more pressing. There are many field examination technologies available in the market that would detect the cracks. However, only limited theoretical methods are available for the purpose. Theoretical examination of the effect of surface cracks to the potential damage of the railhead is essential for a comprehensive understanding of the cracks and crack propagation potential. Although finite element modelling could provide solution to railhead damage, extensive effort is required to mesh the crack tip accurately. This paper reports a two-dimensional model based on

distributed dislocation theory for fracture problems in finite bodies and applied the theory for the analysis of the surface defects in railheads. Both the boundary of the railhead and the surface defect are modelled as continuous distributed dislocations. This method does not require any meshing and hence saves time significantly. Stress intensity factors are evaluated for the surface defects at various locations of the railhead when the railhead is subjected to different loading regimes. The potential propagation of the surface cracks is also addressed in the paper.

## **LONG RANGE INSPECTION OF RAIL USING GUIDED WAVES – FIELD EXPERIENCE**

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**Keywords:** Rail, testing, guided waves, long range, level crossing.

Ultrasonic techniques have been used for many years for the inspection of rail. These measurements can detect the presence of a wide variety of defects but there are practical difficulties with the technology. While large transverse cracks of the type likely to cause catastrophic failure can be detected, the large, critical defects can be masked by large numbers of small, surface defects along the length of the rail. It would be very useful to be able to determine reliably the largest defect size in a length of

rail. Also alumino-thermic welds are difficult to inspect due to the typical defect orientation and the attenuation of the weld material. Guided waves provide a very attractive solution to these problems; they travel along the rail, for tens or hundreds of metres, and are partially reflected by any defects which are present. They are particularly sensitive to vertical defects and they are used at relatively low frequency so they are not significantly attenuated by weld material. With financial support from Network Rail, the authors have developed a practical inspection tool based on guided wave measurements. Initial laboratory tests of the method, together with finite element predictions were presented at the 2002 Railway Engineering conference. This paper describes the design of a pre-production prototype guided wave instrument suitable for site trials. Results obtained at a level crossing are presented that demonstrate the use of the system as a practical screening tool.

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## **REMOTE STRESS MONITORING FOR RAIL MAINTENANCE APPLICATIONS**

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**Keywords:** Structural integrity monitoring, continuous welded rail, stress free temperature, stress monitoring, rail integrity, points connections.

The continuous collection and storage of data describing the state of a structure provides a wide range of advantages over conventional structural maintenance systems. The most significant of these include the overall increase in the safety of the monitored application as well as a potential long term reduction in maintenance costs as the need for intrusive and costly inspection routines is reduced. This is true for many industries including Rail where track inspections often require closure of the line and a significant manual intervention. Recent developments in electronic sensors and data acquisition and transmission systems have led to an increase in momentum in the development of state-of-the-art technology in the field of Structural Integrity Monitoring. One such system is the new Stress Memory Technology (SMT), developed by FIOSTEC Ltd. and University College London. This consists of a self-contained hand-sized monitoring unit which, when attached to the surface of the structure, passively senses and records the occurrence of pre-defined structurally significant events.

This paper presents the application and results of preliminary field and laboratory trials carried out in conjunction with AMEC Rail to investigate the feasibility of SMT for use in Rail maintenance applications. The two selected applications were the monitoring of the Stress Free Temperatures (SFT) in Continuously Welded Rail (CWR) and monitoring of stresses in Points connections. Initial results indicate a high level of accuracy, repeatability and sensitivity of the SMT technology and demonstrate that the systems are sufficiently accurate to monitor stresses in both applications.

## **LIGHTREC: SMALL & LIGHTWEIGHT TRACK GEOMETRY RECORDING EQUIPMENT**

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**Keywords:** Track geometry; track irregularity; two-point method.

A truly portable equipment for recording track geometry named LIGHTREC has been successfully developed to enable real-time measurements on all maintained track. Critical achievements of the development are low cost, light weight, compactness, high precision, heavy duty, and easy operation. These characteristics were achieved by modifying and adopting a unique principle called the two-point angle method for LIGHTREC. Since the new principle needs only one optical encoder to measure irregularities, it has been possible to develop a product model that is lightweight (15kg) and folding (from 2.5m to 1.8m) with a significant reduction in cost (about 1/5). Seven measuring items including track gauge, cross level, alignment (right and left), longitudinal level (right and left), and twist can be measured and calculated to a high precision. As test results on LIGHTREC have proved satisfactory, there are strong expectations that the equipment will find a variety of applications in track quality management.

## **WHEEL – RAIL INTERACTION RESPONSES DUE TO TRACK GEOMETRY IRREGULARITIES**

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**Keywords:** Wheel-rail interface, dynamic responses, track geometry irregularities, wagon and track.

With a view to examining the dynamic responses of the wheel-rail interface, a three-dimensional wagon-track system dynamics (3D WTSD) model was developed and presented widely in the literature by the authors in recent times. The 3D WTSD model consists of three subsystems, namely, a 37 degree-of-freedom (DOF) wagon subsystem, a wheel-rail interface subsystem and a four-layer track subsystem. This paper presents the application of the 3D WTSD model to the examination of the effect of track geometry irregularities on the lateral and vertical dynamic impact forces. The simulated dynamic responses at the wheel-rail interface due to some geometric irregularities, namely, the variation of cross level and gauge are presented. The characteristics of the dynamic responses due to these track irregularities are examined. The sensitivity of the dynamic responses to the variation of cross level and gauge are also presented. It is shown that when the wavelength of cross level irregularity was less 2 m, the vertical impact force exhibited higher rates of increase. It is also shown that the derivation of the gauge face of the rail in the plane of track has pronounced effect on the (L/V) ratio.

# **NEW ULTRASONIC MODELS OF EMBEDDED AND SURFACE- BREAKING CRACKS**

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**Keywords:** NDT, ultrasonic, transverse,  
rayleigh, waves, surface, cracking.

New mathematical models have been recently developed for modelling scatter of high-frequency longitudinal and transverse waves from embedded smooth and rough (corrosion) cracks as well as scatter of the Rayleigh waves from surface-breaking cracks. The models can be used to improve the existing capabilities of detecting and sizing safety compromising cracks in rails and train wheels using piezo-electric transducers.



# **Theme 1: Railway Track**

**Day 1:**

**Safety**



## **SAFETY PROTECTION ISSUES**

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**Keywords:** Safety, trains, track, protective clothing.

Throughout the railway industry there has always been a culture of safety and protection for passengers, train crews, and infrastructure maintenance crews.

Working practices have been improved, operational procedures have been revised and authorities like HM Railway Inspectorate are active in implementing learnings.

## **RAILWAY MAINTENANCE AND SAFETY: ARTIFICIAL INTELLIGENCE LINKS<sup>1</sup>**

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**Keywords:** Artificial intelligence, approximate logic approach, railway safety, safety model.

There are numerous variables interacting in a complex manner which due to the large amount of data available, cannot be explicitly described by an algorithm, a set of equations or a set of rules in the railway assessment. In any situation, there may be both a shortage of key information and an excess of other information. Neural network and approximate logic techniques have demonstrated its usefulness and accuracy in predicting accidents that would occur under different combinations of conditions in some fields in parallel and aviation industries. This paper presents the recent

research result of the development of fuzzy linguistic risk levels using approximate logic approach to deal with uncertainty with our industrial partners. Expert and engineering judgements are then mapped and transferred to neural network models of an intelligent safety prediction system for railway infrastructure safety analysis. It will be evaluating the accuracy of risk predictions made by conventional (statistical) and AI techniques.

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<sup>1</sup>This work forms part of the project on “An intelligent safety prediction system for rail design and maintenance” funded by Engineering and Physical Sciences Research Council (EPSRC) under Grant No. GR/S07292.

## **SAFETY MANAGEMENT ON THE BRITISH RAILWAYS: A SYSTEMIC APPROACH**

### **Jaime Santos-Reyes & Dr Alan N Beard**

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**Keywords:** Risk, railways, system, safety management, viability.

The British railway industry has undergone a number of changes in the years following privatization. Privatization has led to a more fragmented industry and as a result a number of organizations have been involved in the operations, maintenance and renewal of the railway system. In addition to this a number of train accidents, such as the train collision at Ladbroke Grove (1999), the train derailment at Hatfield (2000), and the more recent train derailment at Potters Bar (2002), have highlighted that the current safety management may be inadequate. There is a need for a systemic approach to safety management in the railway industry.

Also, it may be argued that such an approach was necessary even before privatization. This paper presents a preliminary British Railway Safety Management System (BRSMS) model that aims to help to maintain risk within an acceptable range in railway industry operations in a coherent way. It is hoped that this approach will lead to more effective management of safety in the British railway industry.

# **Theme 1: Railway Track**

## **Day 1:**

### **Change in Railway Operation in Europe**



## **OPTIMIZING REGIONAL TRAFFIC ON A SOUTHERN GERMAN REGIONAL RAILWAY BY USE OF THE COMPUTER AIDED RESCHEDULING SYSTEM REGIDISP**

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**Keywords:** Rescheduling, train control, transport control, traffic optimization, intelligent transport.

Optimal rescheduling in cases of delay is important for improving punctuality and service quality in public transportation systems. Since it is impossible to solve the rescheduling task manually, computer aided systems are necessary for this purpose. In the past 10 years the Ravensburg-Weingarten University of Applied Science has conducted research activities in the field of computer aided rescheduling. Since December 15<sup>th</sup> 2002 the Hohenzollerische Landesbahn AG in Hechingen, Baden-Württemberg, Germany is the first regional railway company in Germany to use computer aided rescheduling. This paper deals with the project as well as with the program system used. It shows some practical experiences and outlines possibilities for future use.

## **ECONOMIC EVALUATION METHODOLOGY OF THE REGIONAL TRANSPORT SERVICES IN THE NEW EUROPEAN RAIL SYSTEM**

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**Keywords:** Regional railway, high speed, interoperability, methodology, economic evaluation, rail demand.

This work presents an evaluation of the regional rail transport in the new European scenario (common normative, new infrastructure and new trains). A methodology based on economic exploitation results of these transport services has been used. Case of study: new regional rail service Sevilla-Granada-Almería.

## **CZECH RAILWAYS – THE WAY OF CHANGES**

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**Keywords:** Czech Railways, railway transformation, relationship between Czech Railways, joint stock company and Railway Infrastructure Administration, state organisation.

From January 1, 2003 Czech Railways, state organisation was transformed to companies according the Act No. 77/2002 Coll. - to Czech Railways, joint stock company and the Railway Infrastructure Administration, state organisation. Contemporaneously by this Act the Rail Safety Authority as a new

organisation was also established. The access of rail operators to the railway infrastructure in a neutral and non-discriminatory manner is treated by already novelised Act on Railways from 1994. The Czech Railways, joint-stock company pays for the use of the railway infrastructure to the Railway Infrastructure Administration (like any other rail undertakings).

Czech Railways, joint stock company (the state is 100% shareholder) as an integrated rail undertaking ensures operating of railway transport on the railway infrastructure owned by the state as well as management of the railway infrastructure owned by the state. The Railway Infrastructure Administration, state organisation is a body representing the state as the owner of railway infrastructure. The depreciation allowance for the railway infrastructure is not charged.

The paper shows new positions and mutual relations between new companies and financial as well as technical rules for modernisation, development and maintenance of the railway infrastructure.

## **A SYSTEMS APPROACH TO MONITORING ASSET RELIABILITY**

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**Keywords:** Rail, monitoring, asset, condition, reliability.

Any system obtaining useful information on the state of remote assets needs to perform the following functions:

- Collecting the relevant data.
- Collating data from many different, and often geographically separated, sources.
- Reducing the data to useful information.
- Transmitting this information to where it can be used.

- Displaying the right information to the right people.

This paper outlines some of the issues involved in taking a whole system approach to produce successful asset monitoring systems for the rail environment.

Monitoring systems are not signalling systems, and many of the safety requirements for vital signalling equipment apply, but equally many do not, making safety approval challenging. Monitoring systems can produce vast quantities of data in remote outside locations where conventional IT equipment cannot be used for data reduction. This problem is compounded by the low bandwidth communications links generally available.

Information about an asset is frequently of interest to different parts of the organisation. Monitoring S&C can provide information about physical movement, interlocking with the signalling system and heating in cold weather. System design and operation must cover the differing requirements of all these interest groups.

# **Theme 1: Railway Track**

## **Day 1:**

### **Rolling Stock and Noise**



## **TOWARDS A LOW NOISE RAILWAY SYSTEM**

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**Keywords:** Embedded rail systems, noise and vibration measurements, railway models, acoustical optimization.

The paper reviews the progress made during the research project „Low Emission Railway System (LERM)“ funded by the German Ministry of Education and Research. The construction of test tracks and in-situ measurements of air-borne and ground-borne sound emission is carried out together with partners from academics (IASP at Humboldt University, Berlin), industry (Edilon, Munich) and from railway infrastructure operators (City of Munich). Modelling of the acoustic properties of ballast track and slab track superstructures is carried out at the University of Karlsruhe.

## **DEVELOPMENT FOR SIMPLE TILTING MECHANISM WITH ROUNDED SECTION CAR-BODY (RSC)**

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**Keywords:** Tilting mechanism, car body, comfort.

On curved rail, the speed of train must be reduced in order to keep riding comfort. So, the train has the speed limitation in conventional railway line. But if the train

has the tilting mechanism, the speed of train is able to be increased while maintaining the riding comfort. Generally, the tilting train is faster than the non-tilting train about 30% in curve.

The tilting train technology and reduction of travel time has been carefully investigated by KRRI (Korea Railroad Research Institute). Based on the primary research result from KRRI, tilting control system and tilting operation interface are considered its core technology to apply tilting train to Korean conventional railway. Passenger comfort is controlled by amount of tilted car body. So the smoothness of interface between tilting bogie and car body during the tilting system operation is very important factors to estimate its capability.

RSC (Rounded Section Car-body) can perform tilting operation with non-tilting bogie and non-tilting pantograph without any serious modification. The high tilting technology to control bogie, pantograph and car body can be eliminated in RSC tilting system. Tilting train with RSC can be manufactured easily. It is main advantage of this technology.

In this paper, design requirements of normal tilting train car-body are introduced. And new technology called “RSC tilting system ” is presented with its simple drawing. This technology has been under the patent process. Preliminary or conceptual design is introduced. List of parts and its simple functional description also explained to do synthesis design process. Basic railway safety formulas are introduced to verify operating reliability of RSC tilting system in analysis design stage. Finally, the running test might be expected to demonstrate capability of RSC tilting system.

## **LOCOMOTIVE AUTOMATIC PARKING BRAKE**

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**Keywords:** Locomotive, parking brake, automatic.

This paper provides an overview of the automatic parking brake for the locomotive application. This design replaces the existing handbrake with an automated braking system. The system is controlled from the operator cab or from the walkway of the locomotive. It improves the ergonomics and provides consistent parking brake application. With the automatic capability the electrical system designer can then provide safety interlock and other system level improvements for the locomotive.

## **MODELLING THE STABILITY OF BIMODAL TRAINS**

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**Keywords:** TruckTrain, bogie, bimodal, ADAMS/Rail, UK loading gauge.

The growth of bimodal trains (carrying road trailers on rail, using the trailer frame as the sole carrying structure) is significant in USA, for both general merchandise and serving car assembly plants. There are also applications in Europe. Growth in UK, despite years of interest, has so far been nil, because it is very difficult to operate full 2.5 metre internal height trailers as bimodals in UK.

Current bimodal train speeds are fairly low and trains are long, so overall journey times can also be long. In order to improve on this, a development of the TruckTrain high-power, short FMU [Freight Multiple Unit] concept has been conceived. It takes the form of relatively short but fast bimodal, bidirectional trains (carrying 2.5 metre internal height trailers) to enable JIT [Just-in-Time] services to operate between destinations which are not directly rail-served. The advantages would be short journey and terminal times and minimal terminal costs.

Currently, there is no experience of bimodal trains running at 75-100 mph. The articulated [shared] bogie configuration is also not yet in use for high-speed freight. Equally important is that a key part of the vehicle is the trailer, whose configuration and operation may not be totally within the train operator's control.

The marginal feasibility of accommodating full size 2.5 metre internal height trailers within the UK loading constraints means that effects of instability and exaggerated suspension response (rolling, pitching, yawing and hunting) could both violate the dynamic loading limits and in the extreme become safety problems. We are running a PhD project to develop an Adams-based modelling tool to investigate the stability and dynamic envelope issues of these trains and design rules for suspensions and trailers..

The paper discusses the problems, both those under investigation and the difficulties of building a fully-customisable simulation model with the desired output measures, using the Adams Rail software package. The model is responsive dynamically to changes in the geometry of the bogies and suspension, changes in the suspension parameters and to differences in trailer frame geometry and stiffness. It will report

on movements in roll, pitch, yaw and hunting, in response to a variety of track conditions and range of speeds and on stability of the vehicles and train on the track.

## **VIBRATION AND ACOUSTIC INSIGHT ON HIGH SPEED TRAINS RUNNING ON A BALLAST SUPERSTRUCTURE**

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**Keywords:** Pass-by noise, microphone array, ballast superstructure, high speed trains, rolling stocks wear.

A modern parameter in the global quality assessment of high speed trains is the noise emission. An innovative method for the identification and comparison of mobile acoustic sources was implemented: the microphone array. Basis of the method is the “beamforming algorithm” that from a measure of the acoustic pressure in several points allows to investigate the position and the characteristics of the sound source. This source can be either fixed or moving respect to the array making the method capable of separating different sources among a general noise signal perceived during a vehicle pass-by.

The method was developed using numerical models and proved to be effective testing it on site with different known sound sources both fixed and moving.

After these tests an application of the pass-by noise measurements generated by a rail convoy was investigated. The occasion was given by an experimental campaign

settled for the evaluation of noise and vibration emission of a standard ballast superstructure, within a European research program (“HIPERTRACK”). Results showed the method capability to distinguish multiple sound sources and in particular the possibility to identify the noise emitted by a single wheelset. In this paper an analysis of the noise emitted by the wheel-track interaction of different convoy typologies, on the same ballast superstructure, has been performed and results will be discussed. Comparisons between noise and vibration recorded on the rail showed a good agreement. Time/frequency analysis was finally implemented to identify the emission spectrum associated with every single bogie.

## **ROLLING NOISE REDUCTION BY USING WHEEL DAMPERS**

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**Keywords:** Rolling noise, wheel dampers, acoustic analysis, time frequency transform

The priority, given today to the research of railway traffic noise, depends on always more strict standards of environment, with the introduction of high-speed trains and with requirements on more environment friendly goods transport. Very important noise source that affects the environment is the system wheel-rail. So called rolling noise is caused by vibration of structures of wheels and rail. These noise and vibrations are initiated mainly by shape unevenness (roughness) of both contact surfaces in the contact place. The reduction of the wheel acoustic energy can be achieved by

optimising the wheel design or using vibration and noise absorbers. The absorber significantly contributes to reducing noise of the wheel.

The importance of acoustic and vibration measurements and analyses are unambiguous as from the point of view of human health protection, so from the point of safety, lifetime and reliability of measured establishment, eventually the construction. The precise analysis provides detection and identification of noise and vibration sources and thereby their reduction as well. Theoretical study of this problem, the developed procedure of measurement and analysis and demonstration of real experimental measurement of acoustic-vibration parameters different by various types of rail wheels will be demonstrated in the article.

## **RETROFITMENT OF 1500VDC EMUS WITH THREE PHASE DUAL VOLTAGE DRIVES – INDIAN RAILWAY TARGETS RELIABILITY**

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**Keywords:** Electric traction, retrofit, Indian railways.

Introduction of electric traction at 1500V dc on the Great Indian Peninsula (GIP) Railway from Victoria Terminus to Kurla on 3<sup>rd</sup> Feb.1925 marked the dawn of a new era in the Indian Railways. Subsequently, electric traction was introduced on 5<sup>th</sup> January 1928 on Western Railway, the erstwhile the Bombay, Baroda & Central India (BB&CI) Railway.

The suburban Railway system is recognised as the lifeline of Mumbai. As Mumbai suburban railway network carried 6.1 million commuters everyday, it has highest passenger density in the world,

ahead of even Tokyo & Seoul. More than half of the total daily passengers using entire Indian Railway system are from Mumbai suburban system alone. The increasing population in urban centers has given rise to the need of a mass transit system, where electric traction is the most favoured mode with its well-known advantages. At present, Electric Multiple Unit (EMU) trains plying on the Mumbai suburban section, operate more than 2000 services with a holding of 200 EMU rakes of 9-car. Mumbai suburban railway network is stretched over 240 kms, from Churchgate to Borivli on Western Railway, Mumbai Chatrapati Shivaji Terminus to Kasara/Karjat on Central Railway.

Mumbai suburban railway network, inspite of having heavy demands on it, has provided an efficient and reliable service since the introduction of the first ‘Aag-Gadi’ (Carriage of Fire), brought by the British East India Company. However, the pressure on it continues to increase and has now reached alarming proportions. Overcrowding has grown to such an extent that more than 5000 passengers travel in a 9-car rake during peak hours in the peak direction, as against the designed capacity of only 2700. This amounts to 16 passengers per sq.mtr of floor space, which is beyond the realm of imagination. Described as Dense Crush Load, Super Dense Crush Load and “Practical Loading Limit”, the overcrowding is unparalleled in the world of commuter services.

# **Theme 1: Railway Track**

## **Day 1:**

### **Electrification and Lighting**



# THE INTRODUCTION OF HIGH OUTPUT WIRING TRAINS TO THE UK

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**Keywords:** Electrification, multi purpose vehicle, overhead line, tensioning, train, wiring.

Railtrack's requirements to replace over 700 tension lengths of wire on the West Coast Route Modernisation programme called for a major step change in the type of equipment used and the methodology. In May 1999 the OLE & Distribution Alliance was funded by Railtrack to Design and Build two high output wiring trains each capable of renewing a full tension length of wire in a short midweek possession.

As there was no equipment in use in Europe or the Far East that was suitable to import, the team set about putting together a specification that would meet the stringent performance criteria and the onerous requirements of the UK railway industry.

After discussions with several equipment suppliers, Windhoff, a German manufacturing company was selected as a partner in the development of the new trains. An order was placed in July 1999 and detailed design commenced. The equipment was ready for trials in June 2000 and shipped to the UK within two months.

Vehicle Acceptance Body (VAB) certification was achieved and the first wire run (tension length) was successfully replaced during November 2000. To date over 650 wire runs have been replaced, with the added achievement of a full replacement within a five and a quarter hour midweek possession.



# **Theme 1: Railway Track**

## **Day 1: Signalling**



## **LED CLUSTER TECHNOLOGY IN RAILWAY SIGNALLING**

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**Keywords:** Rail, signals, light emitting diodes (LEDs), LED clusters, optical measurement.

In recent times, the UK railway industry has generated a number of developments involving new technology in signalling. Many of the developments have revolved around the production of light. This paper focuses on recent signalling developments from an optical viewpoint. Examples have been given of the introduction of light emitting diodes (LEDs) into UK railway signals and indicators. The benefits of the signalling developments have been discussed, and the processes of optical testing and assessment have been described. A progress report has also been given of a working party recently set-up to consider and resolve the challenges with optical measurement of LED clusters.

## **DORSET COAST RESIGNALLING USING SIMIS W ELECTRONIC INTERLOCKING**

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Siemens Transportation Systems and Network Rail are working together to introduce new technologies into the UK, commencing with the Dorset Coast Re-signalling Project. Central to the project has been the development of Siemens Electronic Interlocking System, Simis W, to enable it to be used in the UK. This paper and presentation will look at the challenges faced and the solutions employed to make the project a success. It also looks towards the future and the continuing development for use across the entire network.



# **Theme 1: Railway Track**

**Day 1:**

**Rail Design**



# DYNAMIC VEHICLE RESPONSE ON SHORT CIRCULAR CURVES AND TANGENT TRACKS

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**Keywords:** Dynamic response, curves, tangents, tracks.

Various railway companies specify in their track standards a minimum length for circular curves and tangent tracks (i.e. a minimum length between transition curves and/or superelevation ramps) as a function of design speed. Also a draft European standard (prENV 13803-1 Railway applications - Track alignment design parameters - Track gauges 1435mm and wider - Part 1: Plain line) defines such minimum lengths. In an appendix to this draft, the minimum lengths are discussed in comparison with roll oscillations of the vehicles.

When this minimum length cannot be achieved with the preferred radii and lengths of transition curves, the alignment parameters must be changed (changed radii and/or shorter transition curves) and/or the design speed must be lowered. Available terrain corridors may limit the possibilities for changing the alignment.

Hence, the question arises as to whether or not the minimum lengths of elements with constant curvature may justify shorter transition curves and/or lower train speeds.

In this paper, various options in alignment design are analysed, and the dynamic vehicle response is quantified. Tilting and non-tilting vehicles have been simulated with the GENSYS computer code at various speeds on circular curves and tangent tracks with a length of 0-100m.

Vertical wheel/rail forces, track shift forces and wheel climbing ratios as well as

passenger comfort in terms of  $P_{CT}$ , roll velocity, lateral jerk and lateral acceleration have been evaluated according to international draft standards from CEN and UIC.

# INNOVATION IN THE DESIGN OF A NEW RAILWAY IN AN URBAN ENVIRONMENT – SUNDERLAND DIRECT

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**Keywords:** New railways, innovation, value engineering and design.

This paper addresses the key role of innovation in the design of major new railway infrastructure projects drawing upon experience gained by Corus Rail Consultancy's design team from the Sunderland Direct Project.

Christiani and Nielsen teamed up with Corus Rail Consultancy at tender stage and was employed by Railtrack to design and construct the new 5.2km railway running westwards from Sunderland to South Hylton. The line commenced with a new underground station beneath the existing bus station at Park Lane and largely followed the route of a former railway, which had been infilled and converted to a cycleway. Four additional surface stations and various bridges and structures were provided as part of the project.

The contract included everything apart from signalling and the electrification system, which were awarded under separate contracts by Railtrack linked by an alliance agreement to the civils contract.

The structure and organisation of the multi-functional design team and its relationships with the construction and

client teams will be discussed.

Specific examples of design innovation will be provided to illustrate the inter-relationship of design and construction issues including the ground level concourse at Park Lane Interchange, underpinning of existing structures and bridge/tunnel construction.

## **TRACK TRANSITION CURVE GEOMETRY BASED ON GEGENBAUER POLYNOMIALS**

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**Keywords:** Railroad, track, spiral, transition, geometry.

This paper reviews an improved way of approaching the design of spiral transition curves for railroad tracks. The essence of the improved approach is to have spiral design begin not with choice of a geometrical shape for a spiral but rather with choice of a functional form for the roll of the track as a function of distance along the spiral. The paper reviews a natural generalization of the improved approach that supports the design of higher order transition curves. The basic track roll functions that arise in the method are found to be closely related to the Gegenbauer orthogonal polynomials. Linear combinations of the basic roll functions generate transition geometries that are more flexible than geometries based on a single basic roll function and that can be tailored to solve local problems such as inadequate "offset" of a spiral that needs to be lengthened or design of a curve that turns through a small angle. In its general form the method requires use of numerical

integration via a computer program, but closed form solutions can be obtained by means of approximations that are reasonable in some situations.

## **DETERMINATION OF LONGITUDINAL FORCES IN CONTINUOUS WELDED RAIL TRACK USING HORIZONTAL CURVATURE MEASUREMENT OF THE RAIL BENT**

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**Keywords:** CWR track, longitudinal forces, lateral displacements, measuring apparatus.

The proceedings of the last conferences RAILWAY ENGINEERING included the results of investigations carried out at the Gdansk University of Technology related to the determination of strength characteristics of CWR track during control of the track axis [1], [2]. Both the experimental tests and the numerical analysis have proved that the determination of longitudinal forces in CWR tracks is possible by use of the curvature measurement of the rail displaced horizontally by tamping machine.

There has been designed and made adequate apparatus for determining the horizontal curvature. The operational characteristic of the tamping machine provides facilities for the apparatus to measure the track displacements in such a

way that it is possible to separate the rail horizontal and vertical displacement components from the measuring signal. For this purpose a special structure was designed to connect the detecting element with the rail head. To convert the mechanical measuring magnitude to electric voltage value, advantage was taken of differential / capacitance and induction sensors. This type of structure is resistant to any damage resulting possibly from excessive displacements of the track grate and surpassing the measuring range. A testing signal from the sensor is transferred by screened cable to the central electronic circuit to be next registered in the computer. For the curvature measurements use was made of three sensors to test the lateral displacements of the track at some selected characteristic points. The measuring apparatus is installed in the tamping machine without making any constructional changes in the machine. Both the assembly and the disassembly take little time.

By applying the elaborate instrumentation it was possible to perform series of curvature measurements at a stationary testing station and during the machine's current operation in the testing railway track in use. The obtained results confirm the adopted investigation course.

### **3-D FINITE ELEMENT MODEL OF THE RAIL INCLUDING AN ELASTIC FOUNDATION**

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**Keywords:** Rail, elastic foundation, finite element model.

A three dimensional finite element analysis (FEA) model of the rail structure including ties and elastic foundation is developed. The model can calculate stresses in an entire rail for given geometry of rail structure and material properties. Using the results obtained from this 3-D FEA model, stress distribution can be determined. Also an ANSYS design tool is developed for a parametric analysis. Using this ANSYS tool, the stress distribution in the entire rail structure can be quickly determined for various dimensions and material properties of the rail, tie and foundation. This tool saves practitioners an enormous amount of time by allowing them to analyze any rail structure using 3-D Solid FEA rail model on the fly.

## VERY HIGH SPEED RUNNING AND TRACK DESIGN

**Prof Dr EA López Pita & P Fonseca Teixeira**

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**Keywords:** High-speed, track, design, vertical stiffness.

Since the opening of the TGV-Atlantique in 1989, the maximum speed on a commercial operation has been in Europe of 300 km/h. In Japan, the mentioned level of performance was reached in 1997. However, the new line Madrid-Barcelona has been projected to allow maximum speeds of up to 350 km/h. This decision has not been motivated by the wish of breaking a record. It has been simply the consequence of a commercial need: reach a journey time of 2h15 between both cities, located at a distance of 680 km. Only with this level of performance it will be possible to obtain a market share of 60% with respect to the airplane, justifying, at least partially, the investment done on railway. In this context, the current paper has a double purpose: the first, to expound, within the actual state of the knowledge, the theoretical reflections carried out to have a track and a vehicle the most suitable possible to the mentioned speed of 350 km/h; the second, to show the results obtained during the tests at 350 km/h, regarding track vertical loads. The conclusions deduced from the research accomplished show that, with the measures adopted for the track and vehicle, it will not be expected a relevant increase on the maintenance costs of the Madrid-Barcelona line, compared to the ones found on the Madrid-Sevilla high speed line.

## PROBABILISTIC APPROACH IN DETERMINING OPERATION RESISTANCE OF SWITCHES

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**Keywords:** Railway construction, switches, signalling system.

The operation (throwing) resistance of switches depends on the both the design and operation condition. Some of the switch design parameters are defined; some other parameters can be specified as random quantities. As random quantities there can be specified e.g. friction coefficients depending on the lubrication of the slide baseplates, the height alignment of the slide baseplates, the changes of the rail profile due to wear, etc.

For selected types of turnouts there have been developed computation models using the method of finite elements. These models have been applied to compute the parameters of the random quantity representing the operation resistance of switches. The computations have been performed using the Monte Carlo method. Deflection curves of switch rails in the course of setting displacement have been determined. The positioning of setting devices has been optimised.

Maximum value of the throwing resistance of the switches in the course of the setting process has been analysed. Parameters of the random quantity describing this value have been related to parameters characterizing the switch setting and locking device. With respect to required reliability of switch operation there have been defined limiting values of the operation resistance of the switches. These limits have been included in the technical standards of Czech Railways.

## **INCREASING TRAIN SPEED IN TEHRAN-MASHHAD DOUBLE-TRACK LINE UP TO 160KM/H**

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**Keywords:** Speed, track geometry.

The passenger train speed in Iran was limited to 120km/h. Because locomotives were diesel and too old. In recent years, Iranian Railways decided to purchase some high-speed locomotives with 160km/h from Alstom Company, and in 2002 a number of Alstom locomotives delivered to the country. On the other hand, the second track of Tehran-Mashhad line was under the construction and practically interred the service (as double-track) in May 2002. Increasing old track speed, correcting track geometry in some points and also tamping with continues tamping machines and dispatching test trains with the speed of 140 km/h carried out from May to September 2002 as preparations to operate trains with 160 km/h formally. In this paper, the activities carried out as well as the results obtained from test trains described.

## **IMPROVING SPIRAL GEOMETRY OF EXISTING TRACKS**

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**Keywords:** Rail design, spiral, existing tracks.

This paper discusses two problems encountered during planning for field tests of a type of improved spiral, referred to as a  $K_{spiral}$ . The first problem is that the spirals selected as test sites have shapes that are so far from the original design shapes that it would not be feasible during routine track lining to bring them back either to their original design shapes or to the corresponding simple  $K_{spiral}$  shapes. This problem has been solved by a generalization of the  $K_{spiral}$  design method. Illustrations are given of generalized  $K_{spiral}$  shapes that are close enough to the existing shapes so that they can be achieved during routine track lining. The second problem was found by computer simulation of movement of an Acela vehicle over a generalized  $K_{spiral}$ . Simulation at curve balancing speed predicts that dynamic response to the generalized  $K_{spiral}$  will be much better than dynamic response to the corresponding traditional spiral. But, simulation with the vehicle's speed raised to give 9 inches of cant deficiency predicts that dynamic response to the initial choice of generalized  $K_{spiral}$  will be worse than dynamic response to the traditional spiral. The generalized  $K_{spiral}$  can be adjusted to give performance at 9 inches cant deficiency that is comparable to the performance of a corresponding traditional spiral.

## **TECHNIQUES OF ADVANCED DESIGN OF RAILWAY TRACK GEOMETRICAL LAYOUTS**

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**Keywords:** Railway track, geometrical layouts, design methods, symbol calculation technique, numerical calculation technique.

The paper systematizes the currently in use design methods of railway track geometrical layouts. The methods have been divided into two basic groups: those based on the design of the curvature, and the method of direct determination of the system ordinates. From the point of view of the calculation technique applied to each of these groups there have been distinguished symbol calculation technique and numerical calculation technique.

In analyzing the methods related to design of the curvature of the system, particular attention was concentrated on the differential equation method as the most universal one. There has been carried out an analysis of the incorrectly determined system ordinates resulting from the operation of a simplified curvature formula to the symbol calculation technique. In this case a significant improvement the accuracy was possible by taking advantage of the operational calculus. In the numerical calculation technique attention was drawn to the use of genetic algorithms.

The methods of direct determination of the system ordinates by use of the symbol calculation technique are based on finding a solution in the form of explicit function  $y(x)$ . An identification of the problem has

been presented by means of differential equations. The problem of monotonicity can be explained either by searching for a parametric family solution or by an analysis of parameters of full solution. There have been pointed out some constraints connected with the application of solutions based on higher order polynomials. In the numerical calculation technique attention has been paid to the determination of the geometrical layout ordinates by use of evolutionary programming.

## **UNDER ENGINEERING FOR AFFORDABLE RAILWAYS**

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**Keywords:** Mass produced products, short life assets, technology transfer, highway engineering philosophy, short line operation, automatic operation.

Mass produced products applied to rail use would reduce the need for long life systems which are obsolete in the market long before technical obsolescence. The separation of trunk and secondary lines, as on the highway network, with different systems of ownership and maintenance, could help to maintain and expand a national system, with lower costs. Finally full automation would justify economically the replacement of lineside signals by a radio based system, and at last enable rail to offer a service of HGV size consignments at competitive prices and superior service. This would open new freight markets to increase rails share from 7% in the UK, towards the 44% achieved in the US.

# **Theme 1: Railway Track**

## **Day 2:**

### **Asset Management**



## A SYSTEMS APPROACH TO MONITORING ASSET RELIABILITY

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**Keywords:** Rail, monitoring, asset, condition, reliability.

Any system obtaining useful information on the state of remote assets needs to perform the following functions:

- Collecting the relevant data.
- Collating data from many different, and often geographically separated, sources.
- Reducing the data to useful information.
- Transmitting this information to where it can be used.
- Displaying the right information to the right people.

This paper outlines some of the issues involved in taking a whole system approach to produce successful asset monitoring systems for the rail environment.

Monitoring systems are not signalling systems, and many of the safety requirements for vital signalling equipment apply, but equally many do not, making safety approval challenging. Monitoring systems can produce vast quantities of data in remote outside locations where conventional IT equipment cannot be used for data reduction. This problem is compounded by the low bandwidth communications links generally available.

Information about an asset is frequently of interest to different parts of the organisation. Monitoring S&C can provide information about physical movement, interlocking with the signalling system and heating in cold weather. System design and operation must cover the differing requirements of all these interest groups.

## PREDICTING TRACK INSPECTION MAINTENANCE AND RENEWAL REQUIREMENTS USING DECISION SUPPORT SYSTEMS

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**Keywords:** Decision support, asset management, track, maintenance, deterioration modelling.

This paper discusses the development and application of a repeatable modelling capability for predicting work volumes on the national rail network in the UK. The work constituted the major component of a project referred to as the Track Inspection Maintenance And Renewal Review (*TIMARR*), which provided Railtrack (now Network Rail) with a configurable capability for their review of work volumes for Regulatory Control Periods Two and Three.

A “bottom-up” process has been developed which predicts unconstrained renewal work volumes and the inspection and maintenance activities for all plain-line and switch and crossing (S&C) assets for the Control Period’s to 2010. The resulting work volumes were designed to contribute to the track-engineering component of Railtrack’s business plan. The work was conducted on a national basis and has included the modelling of some 20,000 miles of track and 20,000 S&C units.

The systems described in the paper provided the toolset to deliver the *TIMARR* modelling capability but in itself did not deliver the solution. Supporting the application and execution of the toolset was a well-defined and coherent methodology, providing a robust and repeatable process. The work conducted is considered a major step forward for strategic planning and

economic estimations for the UK rail industry and is an integral part of Railtrack's asset management strategy.

The paper concludes by establishing what future steps are now possible and should be taken, through the IT solutions and processes implemented in this work.

## **APPLICATION OF A KNOWLEDGE-BASED INTELLIGENT SAFETY PREDICTION SYSTEM TO RAILWAY INFRASTRUCTURE MAINTENANCE\***

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**Keywords:** Design and maintenance for safety, safety assessment, railway safety, safety.

The Railway (Safety Case) Regulations 2000 requires railway operators to prepare a comprehensive safety case to demonstrate safety by design, by management and by maintenance, to describe operation requirements for continuing safety assurance by regular review and to set out the arrangements for emergency response [8]. Railway infrastructure controllers may use various safety assessment approaches to study all safety-critical elements of trains and infrastructures, operation management and maintenance to optimize safety. This may encourage railway safety analysts to develop and employ novel safety assessment approaches and to make more efforts to deal with railway safety problems. This paper presents a knowledge-based intelligent safety prediction system for rail design and maintenance.

## **EFFICIENT POSSESSION USE AND CONTINGENCY PLANNING**

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**Keywords:** Contingency planning, possession, route capacity.

There are several software packages available which purport to model route capacity. They each use slightly different logic and would therefore each give potentially slightly different answers to the same problem.

Before SMC invested in the package that I am about to demonstrate, we researched the market in depth before choosing OpenTrack to be what we considered was the most versatile package for operations simulation. OpenTrack identifies what we have come to refer to as 'real route capacity', as opposed to 'timetable capacity'. By this I mean that it thinks and re-acts like real signalmen and real drivers and does not restrict its logic to the theoretical rules that underpin the construction of a traditional timetable.

Train Operators want this type of modelling software for two principal reasons. Firstly to identify and model where and how they might improve the timetable by the introduction of additional train paths or other minor changes, and secondly, to try and predict the consequences of 'perturbations'; that wonderfully railway industry word for what the public call 'chaos' – or worse!

# **Theme 1: Railway Track**

## **Day 2:**

### **Track Investigation and Repair**



## **MONITORING TRACK OBJECTS IN THE NETHERLANDS**

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**Keywords:** Track, monitoring systems,  
The Netherlands.

Availability of the railway network is getting more and more crucial. This makes it increasingly important for maintenance contractors to prevent failures at the rail infrastructure that disturb the train service. In addition to this, improving maintenance efficiency remains an important point of interest.

Monitoring crucial track objects is an indispensable tool in this context. To do so, Strukton Railinfra has developed its own monitoring system and has been using this within its Services organisation since 1999.

This system has now been developed into a universal monitoring shell around the objects of the track: POSS, the Preventive Maintenance and Failure Diagnosis System.

## **INSITU TESTS FOR ASSESSMENT OF TRACKBED QUALITY & PERFORMANCE**

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**Keywords:** Track, insitu testing,  
geotechnics, stiffness, soil strength, ballast.

Trackbed quality and performance are governed by geotechnical processes and considerations. Invariably, the characteristics of the ballast, sub-ballast and sub-grade influencing these processes are highly variable beneath any section of track.

Despite the acceptance of this variability, the rail industry tends to adopt methods of investigation which provide only a limited understanding of the extent of the problem. Trackbed designed on poor quality data will inevitably prove to be expensive. If over designed, the overspend will be up front, if under designed the overspend will occur throughout the lifetime of the track in terms of remediation measures. This paper presents the Authors' experience of the use of high quality insitu test data for optimising trackbed quality and design.

## **TRACK-SUBSTRUCTURE INVESTIGATIONS USING GROUND PENETRATING RADAR AND TRACK LOADING VEHICLE**

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**Keywords:** Track-substructure investiga-  
tion, ground penetrating radar, track  
loading vehicle, track stiffness.

Upgrading of existing railway lines for higher axle loads and speeds requires new modern methods for in situ investigation. Combination of measurements of track irregularities, continuous track stiffness and non-destructive geophysical methods like Ground Penetrating Radar (GPR) can be a good example of how important information about the status of existing railways can be obtained. GPR and Track Loading Vehicle (TLV) have been tested on the Swedish Western Main Line where subsoil of very

soft clays under the track has caused a lot of problems. Results from investigations are going to be used for mitigation of excessive settlements, slides and especially environmental vibrations. Track stiffness was measured several times along the track with different excitation frequencies and travelling speed with Banverket's Track Loading Vehicle. Track irregularities have been measured twice a year for several years. The GPR measurement was based on verified measurements that have been done for the Czech Railways. The GPR records were processed into the form of longitudinal sections to the depth of 3 m. Statistic methods have been applied for studies of relations between the parameters measured by the GPR and Track Loading Vehicle.

## **GEOPHYSICS & THE PERMANENT WAY: CURRENT PRACTICE - NEW DIRECTIONS**

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**Keywords:** Geophysics, GPR, electrical imaging, geosynthetics.

Efforts to improve the safety and efficiency of the rail industry have generated interest in both new technology, and the transfer of proven technology from other industry sectors. Geophysics has long been acknowledged as a significant contributor to economic success in the energy and minerals industries, and has achieved an increasing level of acceptance in the engineering and environmental sectors. Recent years have seen the introduction of geophysical techniques to the rail industry such that permanent way geophysics seems likely to become an entirely new discipline.

This paper describes the current range

of geophysical techniques available to the rail industry, discusses concepts under development and examines the potential of other methods in the railway environment.

One particular focus of interest has been the development of 'intelligent' geosynthetics for permanent way applications, particularly for use in conjunction with GPR. PW5 radar detectable geosynthetics [1] incorporate a reflective stripe which generates diffraction hyperbolae (Figure 1) which provide ballast radio wave velocity and can be used for trackbed condition monitoring. Some results of the use of PW5 are presented, together with other novel geosynthetic based monitoring concepts.

## **USING GPR ON RAILWAYS TO IDENTIFY FROST SUSCEPTIBLE AREAS**

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**Keywords:** Railway, ground penetrating radar, ballast, frost susceptibility.

In January 2002, testing was conducted on a 154 kilometres long section of railway between the cities of Tampere and Jyväskylä in Finland. The goal of the study was to define the thickness of the frost-resistant layers between Tampere-Jyväskylä for ballast rehabilitation project and to locate railway sections with the potential for damage resulting from frost heave. Due to the introduction of new high-speed passenger trains, which are more sensitive

to irregularities in the tracks, railway authorities need more detailed information on areas with a risk of developing differential frost heave. One potential tool for quick non-destructive surveys of railway structures and subgrade is ground penetrating radar (GPR).

The other goal of the project was to test the suitability of different GPR antennas for railway surveys. Tests were carried out using GSSI and Radar Team Sweden antennas of different frequencies. The plan was to use high frequency antennas to obtain detailed information from upper railway structures and low frequency antennas to collect information to the depth of maximum frost penetration (3-4 m).

The GPR data, digital video and GPS coordinate data, collected from the railway was processed using Road Doctor software. Ground truth and profile data from the railway section was also linked to the initial data using the same software. This integrated data was then analysed and interpreted using multiple parameters specifically selected for the purpose of locating frost susceptible areas and structures.

This paper will present the key results from the survey and discussions concerning the suitability of different GPR systems and collection techniques for collecting railway data.

## **SAFE RAIL TRACK BED INSPECTION BY HIGH SPEED RADAR**

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**Keywords:** Track bed, inspection, radar, high speed.

This paper describes a new train-borne technology for a continuous inspection of the geotechnical conditions of railway tracks. It is based on ground penetrating high speed radar (GPR). The basic principles of the technology are explained with particular reference to the railway specific tasks. The paper outlines the major differences of the GPR technology compared to the investigation methods of the past. It describes the advantages of the new method in terms of quality and cost benefit. To date, more than 6000 km of railway tracks have been surveyed in different European countries.

## **COMPARISON OF MULTIVARIATE LINEAR REGRESSION AND NEURAL NETWORK ALGORITHMS FOR GROUND PENETRATING RADAR (GPR) ESTIMATION OF TRACK MODULUS**

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**Keywords:** Railroad track monitoring; ground penetrating radar; GPR; modulus measurement.

Ground penetrating radar (GPR) is a non-destructive and non-invasive technology that has recently been applied to assess the integrity of track substructure, including estimation of track modulus. A single electromagnetic pulse of energy at an appropriate frequency is launched into the ground, and reflections from various subsurface layers are recorded. The timing of the reflected pulses provides information on the depth of the layers, while the pulse amplitude yields information on the type of anomalies and subsurface characteristics causing the reflections. In order to perform subsurface imaging, a sequence of such pulses is launched as the system is towed over the surface. There exists a definite relationship between the composition of the track substructure (e.g., layering characteristics, heterogeneities, material migration, etc.) and the GPR image. The track substructure composition also impacts the strength and thus the track modulus. Thus, GPR image characteristics are related

to track modulus, and this relationship can be established based upon coincident GPR and modulus measurements. Using GPR reflectivity values at specific depths, we have developed two models to predict the track modulus within a value of 3.4 MPa (500 lbs/in/in). The first is a multivariate linear regression analysis model and the second is a neural network model. A comparison between the two methods reveals that the neural network technique performs better than the linear regression technique for predicting actual track modulus. However, the former is computationally more intensive than the latter. Both models can be used to predict the track modulus from the GPR measurements and would considerably reduce the time and expense of operational track maintenance strategies.

## **REVIEW OF GPR AS A TOOL FOR THE CHARACTERISATION OF BALLAST**

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**Keywords:** Ballast, deterioration, radar, GPR, investigation, trackbed.

The work is the initial process of an ongoing research project investigating the possibility of uniquely fingerprinting the Ground Penetrating radar (GPR) signal of railway trackbed ballast.

In the last five years (GPR) has become an accepted method of in-situ ballast defect monitoring. Modern GPR systems are

portable and do not require a large number of operators - thus enabling large cost effective surveys to be undertaken.

This paper will review aspects of the current state of research into the investigation and characterisation of railway trackbed ballast.

## **TIME-FREQUENCY TECHNIQUES APPLIED TO TOFD FOR THE AUTOMATION OF RAIL-TRACK INSPECTION**

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**Keywords:** NDT, Rail track inspection, TOFD.

Time-Of-Flight Diffraction (TOFD) is a recent innovation in the non-destructive testing field and has proved a highly versatile and valuable technique for the automatic inspection of welds. TOFD can be used for automatic inspection of rail-track particularly the fishplate and welds areas of the track, which are considered high failure-rate places. Novel Time-Frequency analysis is applied to characterise the TOFD signals and classify defect type. Combining these features with an artificial neural network classifier can provide full automation of the defect detection process. The results of a preliminary study are presented and discussed.

## **GEOPHYSICAL ASSESSMENT OF RAILWAY ASSETS – A PRACTICAL VIEW**

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**Keywords:** Geophysical surveys, cost savings.

Railway engineers face a difficult task in maintaining and improving the network in the face of pressures to reduce the number of people working on the tracks and increase the number of trains running on them. Rail managers have been asked to build a better record of the condition and construction of their assets so that maintenance and modernisation budgets can be spent efficiently. Geophysical surveys are playing a key role in fulfilling these objectives.

Geophysical surveys provide condition and construction information quickly and without significant disturbance or damage to the assets under investigation. Surveys are quick and use highly portable equipment, making for safer work practices than ‘traditional’ methods such as excavation. The results can provide a ‘big picture’, based on continuous rather than point measurements, to enable more cost effective decision-making and better management of railway assets.

It is clear that geophysics offers many existing and potential benefits to the rail engineer – but is it affordable and is it reliable?

A trial hole in a railway trackbed gives information from circa 500mm length of track and might cost £1000. Two such holes might be made by a team in a typical overnight possession. A GPR survey conducted in the same possession might cover 500m of track and cost £3000. On the basis of some ‘back of an envelope’

sums, the trial holes cost £1000 per metre and the GPR £6 per metre.

Geophysics does not just win on cost. Annual tunnel inspections typically include a hammer tapping survey to detect hollow sounding or ‘drummy’ masonry. These cannot get deeper than the first or second brick ring, give different responses with varying moisture levels or brick types, are prone to human error, typically cover just one line along the tunnel and are generally recorded in an ad hoc manner. GPR surveys can cover a wide sweep over the arch, the full depth of the lining, have proven repeatability to remove the human error are positionally correct to within 0.5 of a metre. Yet still hammer tapping is used.

## **MONITORING AND QUALIFICATION OF A NEW TRACK: LONG-TIME DATA ACQUISITION CAMPAIGN AND DATA SAVING STRATEGIES**

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**Keywords:** Rail, superstructure, monitoring.

When a new kind of track is designed and built, an accurate monitoring of quasi-static and dynamic behaviour of the system is required, due to the need of track characterization and for safety and maintenance reasons.

An ad-hoc acquisition procedure has been developed, able to perform triggered acquisition in user definable time windows during the day, select and save only records characterized by some planned conditions on RMS value, peak value etc.

The measurement set-up allows to

monitor the displacement (28 measurement points) and acceleration (14 measurement points) of some track elements (rails, sleepers, slabs, tunnel floor and walls), in addition to 4 light barriers able to trigger the acquisition and give information about train speed and location.

The measurement campaign was 6 months long, producing a big amount of data. Essential was to select a proper data storage strategy, in order to keep the most significant information without saving the whole data. Two approaches were adopted: full data (complete time histories of each channel) and concise data file (only maximum, minimum, mean and RMS values of each channel were stored) saving.

## **TOTAL ROUTE EVALUATION ON ECML FREIGHT PRIMARY ROUTE 3**

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**Keywords:** Trackbed, site investigation, ballast life, track quality, route enhancement.

Freight Primary Route 3 (FPR3) is a potential diversionary route located to the east of the East Coast Main Line (ECML) which, if upgraded, could release existing train paths on ECML for the use of passenger traffic, or provide an increase in capacity for through freight traffic. This paper describes the trackbed investigation required to develop the work scope to provide a fit for purpose, 25 tonne axle load freight route. Trackbed anomalies needed to be identified, along with suggested remedial treatments, taking into account the potential for re-use or continued

maintenance of the existing trackbed.

Trackbed investigation comprised a desk study, Ground Probing Radar (GPR) Survey, Walkover Survey, and Automatic Ballast Sampling (ABS). Further testing comprised ballast particle size distributions and wet attrition values, which were used to determine residual ballast life and ballast cleaning potential. The information was summarised in Total Route Evaluation (TRE) Plots along with HSTRC (High Speed Track Recording Coach) data. Subsequent interpretation produced a summary of trackbed condition, followed by suggested maintenance and renewals options. These were optimised for each section of track, such that maximum use of the existing infrastructure could be achieved.



# **Theme 1: Railway Track**

## **Day 2:**

### **Track Bed Modulus Determination**



# PRELIMINARY DESIGN OF A SYSTEM TO MEASURE TRACK MODULUS FROM A MOVING RAILCAR

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**Keywords:** Track modulus, stiffness, field tests.

Track failure is a major factor in many railroad accidents. Track modulus, or stiffness, is an important parameter in track quality. This paper describes the preliminary design of a system for on-board, real time, non-contact measurement of track modulus.

Measurement of modulus from a moving railcar is non-trivial because of the lack of a stable reference for the measurements. The proposed system is based on measurements of the relative displacement between the track and the wheel/rail contact point. Low modulus track will have a higher deflection under the weight of a passing railcar when compared to stiff track. A laser-based vision system is used to make the measurements. A mathematical model is then used to estimate the track modulus from this data. A mathematical analysis has been performed to determine the best location and minimum amount of data required to determine the track modulus. The full system has been tested in a dynamic simulation and in a laboratory setting. Field tests have also been performed on a stationary railcar under various loading conditions.

Future work will include railcar-mounted higher speed tests in various track conditions



# **Theme 1: Railway Track**

## **Day 2:**

### **Rail Maintenance**



## THE LUBRICATION OF HIGH SPEED CURVES

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**Keywords:** Rail, lubrication, rolling contact fatigue, RCF, remote condition monitoring, RCM.

After the incident at Hatfield in October 2000, Railtrack (now Network Rail) set up a programme to examine and develop a number of initiatives. The increased use of rail lubricators to improve the friction characteristics on curves was identified as an important way to manage and reduce the incidence of Rolling Contact Fatigue on higher speed curves.

At the end of 2001, Network Rail purchased forty electric track lubricators from three manufacturers to be used in a trial to judge their effectiveness and efficiency. Interfleet Technology Ltd assisted Network Rail in the assessment of these units by on-site monitoring and analysis of the data obtained.

For more than a year, Interfleet has monitored the performance of the lubricators installed under different configurations for the trial. The effectiveness of the deposition of grease onto the gauge corner of the rail has been assessed under different route and traffic conditions and five types of lubricant have been included.

An important benefit from the study has been the identification of the feasibility of significantly reducing the number of conventional lubricators in use on the railway network whilst improving the effectiveness of curve lubrication. Although the capital costs of the electric lubricators are significantly higher, they can replace a number of traditional devices in certain

circumstances and show a positive financial benefit within one or two years. Added to this benefit is their improved reliability and the ease with which they can be maintained and adjusted.

## GRINDING RAILS TO COMBAT SURFACE FATIGUE – ARE THERE LIMITS?

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**Keywords:** Grinding, headcheck grinding, shallow curves, gauge corner cracking.

A new form of rail care is gaining ground in Europe. Often referred to as headcheck grinding, the activity aims at eliminating surface cracks on the gauge corner, particularly on high rails in shallow curves. The application now appears routinely in rail grinding programs.

The technical and economic framework of headcheck grinding is still incomplete, but it is considered attractive, because less risky than doing nothing and less costly than changing rail. In the absence of full knowledge of rolling contact fatigue and how it should be treated, current practical questions concern the amount of metal to be removed, the optimal transverse profile to be achieved and the acceptable tolerances of that profile. Major point of interest is whether headcheck cracks should be removed completely, or can be left partly-treated.

This paper summarizes the current practice of rail grinding to counter surface fatigue with particular emphasis on the role of optimal wheel to rail contact. It also deals with potential risks and negative side effects. It closes with an outline of further development designed to optimise the results of this type of intervention.

## **GOOD PRACTICE LUBRICATION OF THE WHEEL RAIL INTERFACE**

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**Keywords:** Lubrication, friction modifiers, wheel rail interface, rail wear, wheel wear, rail RCF.

The friction conditions at the wheel rail interface are critical for effective railway operations. Lack of adequate lubrication causes rapid wheel / rail wear and introduces operational problems. An enduring uniform film of lubricant is needed on the gauge corner along the high rail of curves. Only trace amounts of lubricant are required on the top of the rail. Over-lubrication should be avoided as it has the potential to cause SPADs and other operational problems. Some railways apply friction modifiers to the top of the rail to provide moderate friction levels, whilst friction enhancers are used to increase friction levels at low adhesion sites. This paper provides good practice guidance on the use of lubrication and friction modifiers.

“Good practice” friction management needs to:

- Be a fully integrated element within the overall wheel rail interface management process
- Use lubricants and friction modifiers that: have the required frictional properties for the expected range of operating conditions; are compatible with their delivery system; do not lead to the ineffective operation of vehicle, track or trackside equipment; and do not introduce unacceptable health, fire or environmental risks
- Use applicators that are well engineered to provide high levels of functionality, reliability, inspectability and maintain-

ability. This is most likely to be achieved by solid lubricant or “intelligent” grease spray vehicle-mounted applicators or by electric track-mounted applicators. Vehicle-mounted applicators are preferred to track-mounted applicators because they reduce staff risk exposure, offer a better maintenance environment and avoid the unproductive travelling time to each track location. However, a limited number of track-mounted applicators are still needed to protect critical track locations, like small radius curves.

- Ensure that all applicators receive regular inspections and diligent maintenance by motivated staff that are trained and accredited as competent to perform their duties.
- Use monitoring techniques to provide early identification of applicator faults and allow timely actions to be performed to reintroduce an effective friction management regime.

## **INSTALLATION AND TESTING OF PANDROL VANGUARD BASEPLATES ON MTRC, HONG KONG**

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**Keywords:** Vibration, noise, railways, baseplates, fasteners.

This paper describes the installation and testing of the Pandrol Vanguard rail fastening system at a depot on the MTRC system in Hong Kong. The Pandrol Vanguard system is designed to reduce the level of vibration transmitted from the rail into the ground. The fasteners were installed on each of three slab track test sections in

turn in place of the existing rail fasteners. On each slab, measurements of deflection and vibration of the track were made under a test train both before and after the new fasteners were installed. Direct comparisons of the vibration levels on the track base slab can therefore be made. The measurements show that substantial reductions in base slab vibration were achieved when the Pandrol Vanguard fasteners were installed.

### **INFLUENCE OF TRACK IRREGULARITY & RUNNING PART DEVIATION COMBINATION TO FREIGHT CARS DERAILMENT**

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**Keywords:** Derailment, empty freight cars, track irregularity.

In the paper make analysis freight cars derailment conditions on Russian railways. Describe results theoretical and practical researches on interaction freight cars and track with irregularity. Make a recommendation about regulation track irregularity combination.

### **THERMAL LOAD TESTING OF SOLID WHEELS AT THE SERBIA AND MONTENEGRO RAILWAYS**

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**Keywords:** Railway vehicle, solid wheel, thermal load, long down-grade, longitudinal profile, test.

Basic objective of the solid wheel thermal load testing is to test wheel characteristics, which are important for its thermal load resistance. These characteristics are, above all, wheel temperature and stress state on trains formed of block-braked wagons running on long down-grade lines in JZ network. All tests were carried out on regular trains running on the Belgrade–Bar line. Obtained results were used to estimate wheel rim residual stress level and wheel tread cracks occurrence probability due to thermal loads in operation on JZ network. The following measured values were registered during testing: brake block temperatures, train running speed, train acceleration and deceleration, brake cylinder pressure and brake block activating force. Beside these values, contact thermometers were used to measure tread temperature of the wheels with brake blocks having temperature measuring transmitters (in stations after long middle- and sharp down-grades) and wheels of neighbouring

testing car wheel-set and in terminal stations (Belgrade and Bar) inside wheel surface distances on wheel-sets (buckling) on which the temperature was measured near the contact between the wheel and the brake block. The paper gives results of changes in registered measuring values, depending on time and distance on selected characteristic section (braking in order to maintain constant running speed on long down-grades, braking to stopping after long down-grades, etc), determining maximum and minimum of the measuring values and stating basic comments and decisions regarding the completed tests. For the purpose of calculating the braking power distribution on the line and compare test results with calculations it was necessary to simulate train traction. This simulation was based on the longitudinal profile of the line (characteristic section with long downgrade is shown) and a special developed programme package at the Institute of Transportation CIP for train traction simulation. Calculations of temperature and stress states at the characteristic section were done by the finite element method (FEM).

## **GENERAL TRACK AND OPERATIONAL FEATURE RELATIONSHIPS TO ROLLING CONTACT FATIGUE ON THE BRITISH RAILWAY SYSTEM**

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**Keywords:** Rolling contact fatigue, wheel-rail interface.

A significant amount of data was collected and analysed during the year 2000 and 2001 investigating the causes of and solutions to rolling contact fatigue (RCF) on the British railway system. In the course of the investigations, a number infrastructure features were considered in relationship to RCF. These included:

- Track Curvature
- Line Speed
- Cant Deficiency
- Gradient
- Rail Age
- Rail Type

Within each of these features, data was collected and analysed under a programme of work commissioned by Railtrack, managed by Arup/TTCI, and carried out by the efforts of Railtrack, Arup/TTCI, AEAT-Rail, Corus Rail Technologies, Bakerail Services, and others. The data presented in this paper reflects only a part of what was found during that investigation, and not necessarily what would be found on the railway today.

While data was collected on major British railway main lines, this paper presents only data from the Fast Lines of the East Coast Main Line (ECML) and West

Coast Main Line (WCML). The intent is to provide a general illustration of the effects that the factors listed above were seen to have on the generation of RCF. To present the data from all the routes is beyond the scope and intention of this paper.

It should be noted that the analyses presented in this paper were focused on the track and were absent of factors associated with traffic mix, traffic density and vehicle type. There has been a perspective that RCF is a problem with the infrastructure, and that through adjustments to the infrastructure, it can be solved. This is important because through the analysis of track factors, it became apparent that no clear conclusions or solutions could be drawn looking solely at the infrastructure.

Experience from other railway systems, and further research and investigation on the British railway system show that RCF is not solely an infrastructure problem, but a railway system problem, and includes factors on both sides of the wheel-rail interface. This paper shows that when looking solely at the infrastructure, there are no clear answers.

## **DEVELOPMENT OF ROLLING CONTACT FATIGUE MODELS FOR AN EFFECTIVE PREVENTATIVE GRINDING STRATEGY**

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**Keywords:** Rail, rolling contact, fatigue, grinding, preventative strategy.

The development of a control strategy for the management of rail degradation from Rolling Contact Fatigue (RCF) requires a thorough understanding of the factors affecting the initiation and growth of RCF

cracks, so that a reliable, predictive model can be developed. This will facilitate the timely mobilisation of preventative control measures such as grinding and lubrication. Clearly, the development of such models has to marry the science governing the development of RCF cracks with the practical observations under a wide range of operating conditions. Corus Rail Technologies (CRT) has employed this approach during the development of their RCF models that form part of a suite of Track System Models. CRT has been monitoring a large number of sites both within the Network Rail network, and some other railways, and the data gathered over a three-year monitoring period has been used to evaluate the RCF models developed. The following two approaches have been used to model the development of RCF cracks:

A detailed analytical derivation of the principal stresses within the contact patch, that are then used to calculate the damage per cycle, based on the fatigue life at the calculated equivalent stress determined from laboratory derived S-N data. The primary inputs to the RCF analytical model are the wheel load, wheel and rail geometry, traffic density, and fatigue properties of the material established using torsion testing. The model may be used as an 'on-line' support tool by the track engineer and will provide rail life predictions for given traffic and track conditions almost instantly. The model is being further developed to incorporate an additional module to predict fatigue crack growth rates. Once the model has been thoroughly assessed against observed site data, its simplicity and rapid response make it ideal for undertaking scenario analysis and the development of preventative grinding strategies.

A detailed 3D Finite Element (FE) analysis of the rail-wheel contact provides

the stress inputs to FE-SAFE, a commercially available fatigue initiation software package. This approach was initially used in combination with a 2D FE model of the laboratory Twin-Disc test to calculate the contact stresses, and the position and orientation of maximum shear, and thus crack initiation. The number of cycles to initiation was predicted using fatigue material property data and conventional damage summation rules within FE-SAFE. Comparisons between FE-SAFE predictions and laboratory testing, based on two rail grades, showed good agreement. The method was extended to 3D rail-wheel contact to assess the contact stress conditions for a number of sites in the UK network. Unfortunately, the FE approach is time consuming and ultimately does not support the track engineer in making real time decisions on preventative maintenance. Therefore the FE approach is being used to support the development of the analytical based RCF model.

The RCF analytical model is continually undergoing development, evaluation and subsequent improvement. Once the model has achieved a state of readiness it can be applied to allow the scheduling of preventative measures, such as High Speed Grinding, to ensure that the fatigued material on the head of the rail is removed before cracks become a serious threat to train safety, reliability and availability.

# **Theme 1: Railway Track**

## **Day 2:**

### **Track Bed Properties and Improvement**



## **ASPHALT WITH RUBBER GRAINS AS ANTI-VIBRATING SUB- BALLAST**

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**Keywords:** Sub-ballast, rubber granulate, dry process, damping properties, complex modulus, railway track, loss factor, visco-elastic behaviour.

A wide integrated research has been carried out by Rete Ferroviaria Italiana spa and the Rome University “La Sapienza” to assess the suitability of a new hot mix asphalt (HMA), containing crumb rubber (particle size 2-5 mm), as sub-ballast layer in railway trackbeds. In constructing new Italian railway tracks, a 12 cm bituminous concrete subballast is normally used, to protect the underlying layers or the embankment and to obtain a more performing platform for the ballast. The proposed new mix may be suitable for reducing the vibrations, due to train transits, and to help rubber recycling.

The first part of the research has concerned:

1. characterization of involved materials, with particular attention to crumb rubber properties;
2. design of four bituminous mixes with different kind and content of rubber;
3. evaluation of mechanical properties, included Marshall Stability, indirect tensile test, dynamic complex modulus and fatigue damage;
4. detection of visco-elastic parameters and derivation of master curve, Black diagram and loss factor.

The results obtained and the comparison with traditional HMA show that this new bituminous mixture could really be effective in damping vibrations. The next step will point in tri-dimensional dynamic models, for the assessment of the new material behaviour in railway tracks.

## **KENTRACK: A STRUCTURAL ANALYSIS PROGRAM FOR HEAVY AXLE LOAD RAILWAY TRACKBED DESIGNS**

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**Keywords:** Hot mix asphalt underlayment, railroad trackbed support, trackbed structural design, layer thickness, asphalt tensile strain, subgrade bearing capacity.

The KENTRACK computer program for designing and analyzing various railroad trackbed structural systems is described and utilized throughout this paper. The updated version presented herein contains a user-friendly windows based Graphical User’s Interface. The program is applicable for all-granular trackbed designs and for layered trackbed designs containing a cemented (asphalt-bound) granular layer. Hot mix asphalt (HMA) material has been successfully used as a trackbed support layer (underlayment) in the United States for over twenty years. This paper features the HMA underlayment design and analyzes the components of a typical HMA trackbed while accessing the significance of them to trackbed design and performance. The finite

element method and multi-layered theory are used to analyze trackbed stresses and strains. Measurements from instrumented test and revenue traffic trackbeds are also presented. The effects of various variables on trackbed design and evaluation, as determined and predicted by the computer program, are presented. Subgrade modulus, ballast/HMA thickness and axle load represent three variables that have significant effects on the predicted railroad trackbed service life. Sample calculations using the KENTRACK design program are presented.

## **SUSTAINABLE CLEANING OF RAILWAY BALLAST FOR RECYCLED AGGREGATE**

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**Keywords:** Railway ballast, contamination, cleaning, optimisation, environmental impact

Spent railway ballast is a source of recycled aggregate. Recycling of aggregates contributes to sustainable development by reducing the volume of construction waste going to landfill, reducing transportation and by reducing the impact of primary mineral extraction supplying primary aggregates. Railway ballast is renewed when it loses its geotechnical properties and is no longer able to adequately support the track and provide drainage. Alternatively, ballast is removed from locations where

contamination, primarily by diesel, is unsightly and adds to the characteristic smell of a UK railway station. In this case ballast must first be cleaned before reuse as aggregate. Track mounted systems exist to remove the ballast by vacuum and returning it to the track after processing. Off-site systems are similar to traditional soil and gravel washing plant. An optimised cleaning system can represent savings in both time and money, producing less waste for processing and disposal and returning more materials to the marketplace. Such an approach is in keeping with the overall thrust of sustainable engineering. In this study, the primary factors of contact time, cleaner concentration and abrasive action were investigated for a surfactant-based cleaning agent (Biosolve<sup>®</sup>), applied to contaminated railway ballast using a laboratory-scale cleaning system. It was found a 15 minute wash cycle incorporating a 1% surfactant solution concentration with abrasive action, gave the optimum cleaning efficiency, reducing contamination by 86% from  $17510 \pm 445$  to  $2525 \pm 345$  mg kg<sup>-1</sup>. Several batches of contaminated ballast could be cleaned before significant reduction in cleaning efficiency was observed. Potential environmental impacts of surfactant and hydrocarbon residues were considered and the biodegradability of wastewaters generated with respect to the Biochemical Oxygen Demand (BOD) in wash water, rinse water and leachates produced.

## TESTS ON A TWO LAYERED BALLAST SYSTEM

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**Keywords:** Ballast specifications, track quality, track maintenance.

Considerable evidence suggests that, ballast is the main cause of uniform and non-uniform settlement of railway track, provided the subgrade is adequately specified. Over a period of time uneven settlement of the ballast will cause voids to form under the sleepers leading to unacceptable ride quality of track. Regular maintenance is required to keep track geometry within acceptable limits and to maintain ride quality of the track.

The two layered ballast system proposes to replace the crib ballast by stone of smaller size. The aim is to fill the voids beneath the sleeper as soon as they become unacceptably large and to maintain ride quality of track without use of tamping or stone-blowing. Preliminary model tests have been carried out on the proposed system which indicate good potential for it. The results of the model tests have been validated by full scale tests in the laboratory. The tests have shown that by replacing crib ballast by stone of smaller size a void beneath the sleeper will be filled up to less than, the void size minus the average particle size of crib ballast. The system is self maintaining and keeps track vertical profile within tolerable limits without use of Stone blowing or Tamping machines. Full scale live track trials on the proposed system are planned for, later this year.

## APPLICATIONS AND LONG-TERM PERFORMANCES OF ASPHALT UNDERLAYMENT TRACKBEDS AT SPECIAL TRACKWORKS

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**Keywords:** Hot mix asphalt, asphalt trackbeds, railways, special trackworks, tunnel floors and approaches, bridge approaches, crossing diamonds, crossovers, turnouts, rail/highway crossings, track design, track maintenance, railway track construction.

Since the early 1980s in the United States, CSX Transportation (and its predecessor lines), the other three large Class I railroads, and numerous smaller railroads have been actively involved in utilizing hot mix asphalt (HMA) underlayment during track structure rehabilitation of literally thousands of special trackworks. Typically, special trackworks are more capital intensive to purchase, install, and maintain and the documented life expectancies are many times only a fraction of that obtained on equivalent lengths of open track sections. It is often difficult to obtain and maintain adequate drainage in the vicinity of special trackworks. The added impacts stemming from track geometric deviations, rail irregularities, and vertical track stiffness variations tend to shorten their service lives.

The majority of the special trackworks underlain with HMA underlayment had previously required abnormally intensive maintenance at the specific locations to

continuously maintain conformance to the specified track geometric parameters for the particular class of track. These maintenance expenses not only strain engineering budgets, but also have a negative impact on operating efficiencies on the major line haul routes. Documented cost savings from numerous installation sites indicate the minimal increase in initial costs to install HMA underlayments is often recovered in less than a year.

Numerous types of special trackwork installations are described. These include: 1) tunnel floors and approaches; 2) bridge approaches; 3) railroad crossing diamonds, crossovers, and switch turnouts; and 4) rail/highway at-grade crossings. Significant details are provided relative to the unique conditions and situations associated with each type of special trackwork. Brief descriptions are presented for representative projects.

## **BEHAVIOUR OF RECYCLED RAILWAY BALLAST BASED ON LARGE-SCALE TRIAXIAL TESTS**

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**Keywords:** Deformation, degradation, railway ballast, recycled ballast, settlement, strength.

The findings of a series of monotonic triaxial compression tests conducted at low confining pressures were used to predict the shear strength and deformation and

degradation characteristics of model fractions of recycled railway ballast. The effect of particle size distribution, shape and maximum principal stress ratio on the deformation and degradation behaviour of recycled material was studied. It was observed that if the unwanted fines were removed, the recycled aggregates exhibited quite acceptable mechanical properties when compared with fresh ballast. It might be possible that recycled ballast could be used for the construction of railway tracks and in this way keep the maintenance cost to a minimum. It is however necessary to establish the behaviour of the recycled ballast under similar loading conditions as those encountered in the track. For this purpose, a unique testing device was designed and built in-house in order to perform cyclic triaxial tests on fresh and recycled ballast, including simulation of the field load and boundary conditions. This paper deals with the findings of this testing program that shed further light on the way towards cost-effective maintenance of railway tracks.

## **VIBRATION BEHAVIOUR OF RAILWAY TRACKS FOR NOISE AND DAMAGE PREDICTION**

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**Keywords:** Railway track, vibrations, dynamics, recording, design, assessment.

A railway track is the object, which is necessary for the support and the guidance of a railway vehicle. The use of a railway tracks by a railway vehicle causes dynamic loading, which generates vibrations in the interacting systems of train and track. The vibration behaviour of the railway track in the mid- and high-frequency range (40-400

Hz and 400-1500 Hz respectively) can act as an indicator for its performance with respect to sound radiation, vibration sensitivity and wheel-rail interaction forces. These aspects should get more attention of railway track managers, on the condition that a well qualified and - even better - a well-quantified performance indicator is available. A suitable guiding instrument, providing such an indicator for track design and track maintenance, has been developed in the course of the research project Dynatrack (De Man, 2002), and it has been used in an increasing number of cases. This article will pay attention to some basic performance examples of various railway tracks in the field of vibrations. Recordings and simulations will be presented and the effects of various component properties will be illustrated. The performance, which is expressed in integral values, is easily compared for the various track types, components, designs and conditions.

## **PERFORMANCE OF SHELL-TYPE TIES UNDER RAILWAY TRACKS**

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**Keywords:** Railways; tracks; shell-type ties; flat-bottomed ties; experimental investigation.

Railways constitute the largest and the most expensive project governments or private entities undertake. The deterioration of their tracks represents a major and outstanding

problem for railways and transportation around the world. Railway tracks consist of ties (sleepers) equally spaced, on a well-compacted granular material (ballast). These ties are usually made of uniform wood or reinforced concrete sections with flat bottom. This design persists in spite of the high cost of maintenance and replacements. A possible improvement to the design of ties is to implement the concept of shells. This design will significantly improve the performance of the tracks, in terms of higher bearing capacity, lesser settlement and accordingly less maintenance costs as compared to the conventional flat ties.

This paper presents the results of an experimental investigation on prototype models of shell-type and flat-bottomed ties. The study was directed to determine the geotechnical performance of these ties, in terms of bearing capacity and settlement characteristics. Based on the results of this investigation, prestressed concrete shell-type ties may be easily adopted to railway tracks. Such a design, will lead to economical ties that utilize the concrete and the supporting material more effectively and accordingly reduce their maintenance costs.



# **Theme 2: Railway Structures and Earthworks**

**Day 1:**

**Earthworks Assessment and Management**



## MANAGING THE RAILWAY EARTHWORKS ASSET

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**Keywords:** Earthworks, asset, management.

Railway infrastructure is complicated and many of the assets are interrelated. The maintenance of the earthworks involves maintenance of the associated assets. If they are properly looked after, then the earthworks will require little or no maintenance. This paper discusses the interrelationship of the different assets and the benefits of adopting a fully co-ordinated approach to maintenance and asset management.

## EARTHWORKS ASSET ASSESSMENT USING REMOTE SENSING

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**Keywords:** Remote sensing, highways, earthworks asset management, infrastructure earthworks, Airborne Laser Scanning (LiDAR), pilot scale trial of remote sensing techniques, earthworks condition assessment.

The Highways Agency (HA) in the United Kingdom is responsible for managing 9,760 km of the motorway and trunk road network in England on behalf of the Department for Transport, (DfT). The most recent figures available indicate that the Highways

Agency is spending upwards of £12m per annum on 'reactive' slope repair and that year on year costs are increasing almost exponentially. This together with the requirement to increase capacity and reliability of the existing network have led the Highways Agency to institute a 'pro-active' earthworks management strategy.

One of the key requirements for the development of such a 'pro-active' asset management strategy is the regular survey of current detailed asset inspection / condition data. Helicopter and fixed wing aircraft borne laser scanning (LiDAR) offers the opportunity of rapidly obtaining detailed digital ground survey data of large lengths of the highway asset, with the ability to survey some 100km of linear asset per day.

The key product of the laser scanning is a detailed ground survey and this provides the potential for using advanced 'change detection' techniques to digitally compare surveys and 'automatically' identify areas of noteworthy earthworks deterioration. This would potentially allow more focussed ground inspections, with benefits in terms of speed and the reduction in exposure of staff to the hazards of working on live highways.

With substantial areas of the network to review on a regular basis, an HA research programme has been initiated to evaluate the potential for LIDAR systems to identify 'condition features' and the practicality of 'automated change detection'.

This paper will describe the results from a trial on 20km of the M25 Motorway and outline the potential for rapid population of earthworks asset condition databases using remote sensing techniques.

Various operators of other infrastructure networks such as London Underground Limited, Railtrack Great Western Zone and the British Waterways Board have been

closely involved with the research, recognising that similar techniques will have application in areas such as Railways, Flood Defences, Canals, Dams etc.

## **RAIL ROCK SLOPE RISK APPRAISAL**

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**Keywords:** Railways, rock slopes, stability, risk, appraisal, management.

Effective management of earthworks on transport infrastructure networks requires knowledge of their number, location and of the risk posed to the infrastructure and users. Network Rail (formerly Railtrack) has been working to improve pro-active management of earthworks on the rail network. As part of these improvements Network Rail, WA Fairhurst and Partners and Babbie entered into a joint venture to develop an improved risk based approach to managing rock slopes – the Rail Rock Slope Risk Appraisal (RRSRA). The general approach adopted in development of this system is based on the logic of the TRL Rock Slope Hazard index and Quarry Rock Slope Hazard Index as published by McMillan and Matheson 1995, 1997, McMillan, Nettleton and Harber 1998 and McMillan and Nettleton, 2000.

The RRSRA is based on rapid field surveys that record essential data on geotechnical conditions of the rock, rock slope geometry and track alignment and exposure to hazard. These data are then used to derive parameter values that are in turn used to calculate the RRSRA value via a standard calculation path based upon event tree risk assessment logic. This RRSRA

value is used to determine the condition status of the rock slope as:

- Serviceable
- Marginal
- Poor

These condition assessments are then used in prioritising further action and repeat monitoring surveys. The system has been used in a trial implementation in the North West Region where it has been used to survey all rock slopes in the Region (approx. 1800).

This paper will describe the basic principles behind the approach employed in the RRSRA and report the preliminary findings of the North West Region trial.

# **Theme 2: Railway Structures and Earthworks**

## **Day 1: Earthworks Stabilisation**



## **RE-ALIGNMENT OF RAILWAY TRACK TREBOVICE – RUDOLTICE (CZECH REPUBLIC), TUNNEL OR OPEN CUT, ANALYSIS OF GEOTECHNICAL HAZARDS**

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**Keywords:** Geotechnical, realignment, clays.

Track section Trebovice – Rudoltice on the border between Bohemia and Moravia and European watershed is one of the most complicated sections in Czech republic from the geotechnical point of view. Main difficulties in that area result from expansive clays with high plasticity. Swelling of these clays caused destruction of the Trebovice tunnel built in 1842-1845. This tunnel was restored after great difficulties in 1932.

Modernisation of railway track in that area was solved by re-alignment of existing tracks. Crossing through the soils with the worst mechanical properties (highly plastic expansive clays) was designed as cut-and-cover double-track tunnel protected by diaphragm walls with invert.

Contractor that won the tender suggested solution with open cut and proclaimed significant reduction of costs.

Stavební geologie – Geotechnika a.s. was asked to analyse geotechnical hazards of both solutions from short and long term point of view. At the first stage it was necessary to prepare open cut solution on the same level as tunnel design to make comparison of them.

Due to time shortage a limited site investigation was carried out and limited numerical analysis (FEM) was made. Results of this stage were summarised in statement that open cut is not possible to

construct without additional technical measures (retaining walls, stabilisation of soils, dewatering).

Suggested measures were integrated into design that was analysed in comparison with tunnel one. All main geotechnical hazards – expansive clays, saturated sands on the top of clays, removing off significant amount of material without subsequent compensation, crossing with existing tunnel, etc.- were solved by both designs.

Comparing of life cycle costs of both solutions it was found out that open cut solution is less favourable than tunnel.

Final solution (tunnel or open cut) has not been selected yet (February 2003).

## **STABILISATION OF EMBANKMENT WITH DIFFICULT ACCESS AT BELFORD, NORTHUMBERLAND**

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**Keywords:** Embankment, railways, stabilisation, duckbill anchors, difficult access.

A 130m long section of the Belford Upside embankment runs at the crest of a disused quarry. The embankment is up to 7m high with variable slope angles from 35° to 40°, and was constructed using cohesive glacial till. The over-steepened slopes have led to significant ballast movement, resulting in undermining of cable troughs, leaning fences, inadequate cess width and requiring regular tipping of ballast to prevent undermining of the track. The ballast has extended into the quarry outside the railway property boundaries. Stability analysis indicated that the embankment slope was unstable. The remedial works consisted of three to four rows of duckbill type anchors

to stabilise the embankment. The top row of anchors provided stability to a gabion retaining wall required for cess widening. The duckbill anchors were chosen because the difficult access, as the works could only be entered from one end of the embankment. The anchors were driven using lightweight skid mounted equipment. During proof loading, the upper and middle rows of anchors showed a capacity lower than that required by the design and previously confirmed by load testing. A limited number of additional anchors were installed. The paper discusses the choice of anchors bearing in mind the access restriction, the preliminary trials and their subsequent installation and testing.

#### **SOIL-NAIL TRIAL AT LEOMINSTER HEREFORDSHIRE – A CASE STUDY**

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**Keywords:** Ballast, formation, ground improvement, settlement, soil nails, subgrade stiffness.

With increasing pressure for higher line speeds, heavier axle loads and the need to reduce maintenance costs there is a necessity to develop in-situ ground improvement techniques that can be applied between sleeper cribs or through the ballast shoulder. This paper describes a full-scale trial of the soil nail technique undertaken on a live track at Leominster, Herefordshire.

There is discussion on how this technique was used to improve the stiffness of the railway subgrade without removing any of the track components, on its ease of application, and its effectiveness. This trial, which is funded by the government approved EPSRC LINK programme, formed part of an ongoing research project called Improving the Stiffness of Existing Rail Track (ISERT).

#### **LEDBURN JUNCTION: A CASE STUDY OF RAILWAY EMBANKMENT STABILISATION**

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**Keywords:** Embankment stabilisation, piling, temporary works, partnering, Gault clay, earth structure remediation, railways.

As part of the West Coast Route Modernisation a new high speed junction has been constructed immediately south of Train Robber's Bridge at Ledburn embankment. The embankment has proved a historically high maintenance structure and consequently stabilisation of the embankment has been integrated with the modernisation.

Instability of the embankment was indicated by deformation of the track and services and by the irregular slope profiles.

Extensive ground investigation followed by geotechnical modelling was carried out to identify failure mechanisms and allow design of both the remedial measures and the foundations for new overhead gantries. Shear surfaces in the embankment foundation with a low residual strength were key to the observed deformations.

The low factor of safety of the embankment required a structural solution and piling was chosen. Special measures were required to ensure safe construction within the railway environment. The associated buildability and safety problems were solved by utilising the strengths of the whole team, for example this enabled the temporary works to be incorporated into the permanent earthworks. This integrated approach to design and construction required close Client-Designer-Contractor working relationships and this was reflected in the ability to meet the tight programme whilst adapting to on site conditions.

## **INNOVATIONS IN EROSION CONTROL ON RAILWAY STEEP SLOPES (BATTERS)**

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**Keywords:** Erosion control, steep slopes, batters, drip irrigation, railway.

Research into cost-effective strategies for erosion control (HEFRAIL Project) on railway earthworks steep slopes (batters) in Central Queensland, Australia, has established that 100 % grass cover reduces

erosion by over 90 % compared with the bare scenario. The strategies are centred on amelioration of the largely dispersive, sodic, saline and extreme pH in-situ or borrowed subsoil of the earthworks, provision of a cheap mulch (waste ballast or erosion control blanket) to protect grass seeds/seedlings and ameliorants from washout by rainfall events, and development of a cost-effective drip irrigation system. This paper presents innovations of the cost-effective erosion control strategies demonstrated at selected field trial sites throughout Central Queensland. Although the erosion control strategies have been developed for semi-arid environments, it is believed they have potential in humid environments as well.

## **SOIL SLOPE HAZARD INDEX AS A TOOL FOR EARTHWORKS MANAGEMENT**

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**Keywords:** Slope, hazard, index, earthworks, management.

Network Rail has a £multi-billion asset at the heart of its operations – the earthworks on which the permanent way is founded. Management of this asset is fundamental to the safe and efficient operation of the network. The consequences of failure are serious with disruption of operations probable and in extreme circumstances can lead to complete loss of support to the line and serious injury to staff and passengers.

In past decades asset management has tended to be more in response to failures.

In recent years Railtrack/Network Rail has moved to a strategy of proactive management. This has been achieved through the assessment of earthworks structures and the use of alliance partnerships for physical improvements in a systematic manner.

Network Rail has commenced a phased review of their entire earthworks asset to further improve the level of proactive management of the asset. The approach adopted in the NW Zone is to produce a Soil Slope Hazard Index (SSHI) for every earthworks structure. This will provide baseline data for future cyclical inspections and provide a guide to current performance. The SSHI is derived from basic data and is intended to provide a method for comparing the relative condition of each earthwork and for monitoring changes to individual structures. It is intended to provide a logical, ordered and repeatable system for management of the earthwork asset.

# **Theme 2: Railway Structures and Earthworks**

## **Day 2:**

### **NDT and Monitoring of Rail Bridges and Retaining Walls**



## **USE OF THE MEGASCAN™ IMAGING PROCESS IN THE INSPECTION OF RAIL BRIDGES AND OTHER MAJOR STRUCTURES**

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**Keywords:** Megascan, NDT, bridges, concrete, inspection, radiography, railways.

This paper reviews the Megascan™ Imaging Capture System, which is a radiographic technique used by Material Measurements Ltd (MML) in the investigation and assessment of railway and other civil engineering structures. Reference is made to the key role that the Megascan™ Imaging Capture System currently plays in post-construction inspection and assessment.

## **STRAIN MEASUREMENT, CLYDE VIADUCT**

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**Keywords:** Bridges, strain, monitoring

Fugro Structural Monitoring (FSM) was requested by Mowlem (under the direction of Babbie Group Ltd) to perform strain monitoring on a bridge over the River Clyde near Crawford, Scotland. The purpose of the exercise was to examine the strains at various locations on the four main girders, due to trains passing over the structure, and determine whether the bridge could be considered as a continuous structure rather than comprising discrete elements. Monitoring of the bridge was performed in May 2001.

## **NOTES ON THE ASSESSMENT OF RAILROAD MASONRY RETAINING WALLS**

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**Keywords:** Masonry, retaining walls, defects, NDT, standards.

This paper covers non-destructive testing (NDT) techniques suitable for the investigation of retaining walls. Each method is considered and evaluated as to its suitability for the investigation of problems associated with retaining walls. A series of possibilities for numerical modelling of the NDT retaining walls is considered.

Recommendations are made as to possible strategies are made. A case study is given of a retaining wall investigation.



# **Theme 2: Railway Structures and Earthworks**

## **Day 2: Bridges**



## **DEFECTS, INVESTIGATION AND REPAIR OF A THREE-SPAN MASONRY ARCH BRIDGE**

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**Keywords:** Bridge, masonry arch, repair.

The three span masonry arch described in this paper was constructed in 1837 and carries an unclassified road across the two track railway just North of Merstham. Originally built as a private access road for a local landowner Sir William Jolliffe, the construction of the M25 and M23 motorways surrounding the village of Merstham means this railway crossing is now an important link for local traffic.

This paper describes the discovery of unusual structural defects and subsequent rapid deterioration in the condition of one of the piers. Vertical fractures extending from below mid height towards ground level were observed to grow quickly in length and width accompanied by local crushing failures. Investigation into the causes of the defects is discussed along with the options for repair. The final remedial works had to be implemented with utmost care in order to avoid further distress to the deteriorating pier.

Utilising a mixture of modern and traditional monitoring techniques the railway was allowed to remain fully operational during the delicate repair operation. Investigation, design, temporary, and permanent repairs were completed within just 32 weeks and the road opened to traffic incorporating new features designed to enhance the safety of road users and the railway.

## **CASE STUDY: TEMPLE MILLS VIADUCT AT STRATFORD CTRL INTERNATIONAL STATION**

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**Keywords:** Curved integral reinforced concrete structure, soil-structure interaction, multi-disciplinary design.

Stratford International Station is being constructed as part of the Channel Tunnel Rail Link. A connection, located at Stratford Station, is required from the CTRL main lines to the site of a nearby maintenance depot for CTRL trains. Within the station this link, Temple Mills Viaduct, starts at CTRL grade, rises through a central domestic platform, curves over the three down lines and international down line platform and connects to a retained cut outside the station structure. The main structure is an integral reinforced concrete portal, supported on piled foundations to one side and directly connected to diaphragm wall panels on the other. This paper will discuss the constraints involved in the concept design of the viaduct, the interfaces between the various disciplines involved in the design and construction of a major new railway station and the main issues affecting the detailed structural design and construction.

## **INSTALLATION OF LONGITUDINAL TIMBERS ON GLEANN VIADUCT**

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**Keywords:** Railway, bridge, longitudinal timbers.

This paper describes design development and installation of a track support system based on longitudinal timbers, at a remote site on the Glasgow to Fort William railway in western Scotland. The provision of longitudinal timbers, in place of the ballasted track bed previously present on the bridge, achieved a sufficient reduction in weight to permit the continued passage of freight traffic, without recourse to the extensive reconstruction which would otherwise have been necessary. The remoteness of the site and the difficulties of access presented particular challenges to execution of the project.

## **LOW PROFILE RAILROAD BRIDGE DESIGN**

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**Keywords:** Bridges, steel, low profile.

Through-girder bridges have been used for many years as a low profile between the rails and the bottom of the girder. However, to construct today requires a great deal of labor-intensive steel fabrication. While the price of steel has not risen in recent years

the cost of fabricating steel bridges has risen significantly. We decided to try to minimize the fabrication costs while maintaining all design requirements.

We designed a unique low-profile steel box girder section which has low fabrication cost and minimizes required maintenance. A 100 foot span was designed with a depth between bottom of girder and top of rails of 5'-4" which meets the stiffness requirement of AREMA (live load deflection limit of  $L/640$ ).

The box girder consists of three-cells with steel bottom and web plates composite with a folded concrete deck. The folded deck forms the trough for the railroad ballast. Expensive diaphragm fabrication is avoided due to the inherent torsional stability of the box section. The proposed bridge was successfully built at a substantial savings over a traditional through-girder bridge.

## **STRENGTHENING OF RAILWAY UNDERBRIDGE D141 AT BROMLEY-BY-BOW**

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**Keywords:** Bridge, strengthening, steel.

Bridge D141 consists of two 60m span steel through truss bridge located east of Bromley-By-Bow Station. It carries the eastbound and westbound District lines over the River Lea and Bow Creek. The bridge was constructed in 1889.

Inadequate maintenance of the bridge had resulted in extensive corrosion of the deck, the truss members and the wind bracing. In addition severe wheel unloading was recorded on the bridge and a speed

restriction of 15mph was imposed on the eastbound track. The bridge was assessed in 1995 and found to have insufficient strength to carry the full RL loading.

Following an extensive feasibility study, the bridge was refurbished and strengthened by replacing the rail bearers, and the wind bracing. Plates were welded to the cross girders where these were corroded. The whole track system was replaced using flat bottom rails fixed onto standard timber sleepers embedded in transverse troughs. The whole bridge was blast cleaned and repainted.

The strengthening was carried out over 18 no 52 hour and 4 no 27 hour weekend possessions allowing the bridge to be opened to normal traffic during weekdays.

As a result of refurbishment and strengthening works the life of the bridge has been extended by another 100 years.

## **CONTINUITY EFFECTS IN COMPOSITE STEEL – CONCRETE RAILWAY BRIDGES**

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**Keywords:** Composite bridges, cracking, tension stiffening, creep, shrinkage, stresses, deflections.

The structural analysis of continuous composite steel-concrete bridge beams subjected to instantaneous and sustained loads is presented. In the first part of the paper the non linear effects due to concrete cracking in the zones with negative moments are investigated by deriving the moment – curvature relationships, taking

into account tension stiffening and concrete creep. Then the general compatibility equations governing the structural analysis according to the Force Method are deduced and a general non-linear algorithm for their solution is proposed. In the second part of the paper, referring to continuous beams for which the imposition of downwards displacements of the internal supports can prevent cracking, the long term structural analysis is developed in detail. A case study regarding a two-span bridge is finally discussed, pointing out the basic aspects of the non-linear behaviour of cracked continuous composite steel – concrete bridge beams and the advantages that can be obtained by introducing downwards displacements at the inner supports.

## **RECONSTRUCTION OF UNDERBRIDGE NO. 122 (NAJ2) CHEARSLEY**

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**Keywords:** Reconstruction, bridge, railway, girder, abutment.

Bridge deck renewals are frequently carried out throughout the railway network during very finite timescales. Quantitative Risk Assessments (QRA) are undertaken in order to manage the risks involved and avoid over-running. This results in the incorporation of contingencies built into programmes to allow for the unforeseen and method statements are produced in order to clearly sequence the operations to be done.

This paper describes the establishment of the Structures Framework Contract and then goes on to describe the conception, design,

fabrication and installation of Underbridge No. 122 on the Chiltern Line between Neasden and Aynho Junctions at 32 miles and 1282 chains; a typical reconstruction. A twin standard box girder superstructure with the retention of the substructure has replaced the existing structure, which comprised a half-through arrangement of riveted plate girders.

# **Theme 2: Railway Structures and Earthworks**

## **Day 2: Tunnel Investigation**



## **VIDEOGRAMMETRY AND NON-DESTRUCTIVE TESTING OF VICTORIAN RAILWAY TUNNELS**

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**Keywords:** Masonry, survey, non-destructive, tunnels.

Haswell Consulting Engineers have recently inspected two Victorian brick lined railway tunnels – Silvertown Tunnel in London’s Docklands, and the Central Gasworks Tunnel at King’s Cross.

In order to obtain a complete photographic record of Silvertown tunnel, a 3-dimensional videogrammetrical survey was undertaken. This not only produces a complete photographic historical record of the tunnel, but also allows the viewer to ‘walk-through’ the tunnel on their computer. Because the images are taken from known locations, measurements can be taken from the images on a computer and downloaded directly into a CAD drawing system to produce survey drawings. If enhanced detail is required on a particular structure, then second or subsequent visits to the tunnel are not required, because all of the information is obtained within the images.

Ground probing radar, together with brick coring and testing, were utilised on the Central Gasworks Tunnel at King’s Cross to determine if any delamination, or voiding was present within the brick rings. This very quick method of investigation ensured that one wall of the 485m long tunnel could be examined within one 6-hour night time possession.

## **A NOVEL SYSTEM TO MEASURE RAILWAY INFRASTRUCTURE**

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**Keywords:** Rail, track, structure, tunnel, bridge, gauging, laser, optical, vehicle, land rover.

There are around one hundred thousand structures on the UK’s rail network. Each of these structures needs to be measured at frequent intervals to check that clearances are sufficient to allow the safe passage of rail vehicles. Laser Rail have developed a novel, non-contact system to measure the internal profiles of railway structures at speed. Currently the measurement system is mounted on a road-rail Land Rover.

The measurement system consists of lasers mounted around the body of the vehicle to provide an illuminated slice of laser light, and nine digital cameras which view and measure the image. This method of optical triangulation has the advantage of producing continuous cross-sectional data as opposed to the helix shape created by scanner systems. Seven cameras are used to view the profile and two are used to view the rails. A composite profile is built up by storing the nearest points to the vehicle for each camera over distances of 1m or 5m.

The two rail cameras provide a close up view of the running edge of the rail. Rail wear and condition of the rail can be determined from this data. This paper will discuss the data produced by the system, the accuracy of the data, the limits of the system and future applications.

# INVESTIGATION OF CONCRETE TUNNEL LINING: IN-SITU CONCRETE EXAMINATION USING A SHEAR WAVE ULTRASONIC TECHNIQUE

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**Keywords:** Concrete, NDT, tunnel lining,  
UPE, GPR, ultrasonic pulse echo.

A rapid ultrasonic pulse echo technique has been used with great effect to scan the concrete lining of two railway tunnels. The instrument used was the A 1220 from MSIA Spectrum, Russia. Working side-by-side two engineers from Force Technology were able to make a full and detailed survey of the concrete thickness and homogeneity along 1300 m of tunnel. To our knowledge this survey is the first of its kind worldwide that can show such high resolution over an area covering some 10.000 sq. meters.

# **Theme 2: Railway Structures and Earthworks**

**Day 2:**

**Tunnelling:  
Ground Movement and Vibrations**



# **EXPERIMENTAL INVESTIGATION ON EFFECTIVENESS OF REDUCTION OF TRANSMITTED VIBRATION, DUE TO TRAIN TRANSITS, OF DIFFERENT TRACK SYSTEMS IN UNDERGROUND APPLICATIONS**

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**Keywords:** Vibration attenuation, track systems, wheelset-track interaction.

In this paper, the effectiveness in vibration attenuation due to different track systems is experimentally evaluated by means of vibration measurements, on several sites in Milan underground. The vibration measurements performed in the tunnel, at the ground level and in the buildings nearby, enable to obtain the attenuation transfer functions between all these different locations. The same transfer functions can be used to evaluate the variation in the disturbance level into buildings, guessing a change of the track system typology. A results interpretation is also carried out, with a simple analytical model of wheelset-track interaction.

## **NEW SUBWAY AT KINGSBURY**

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**Keywords:** Railways, possessions, planning, bridges, sliding, underground services.

Network Rail's (formerly Railtrack's) Cross Country Route Modernisation (CCRM) Project was conceived to enhance existing

railway infrastructure to enable the latest generation of trains fulfil their performance potential. In order to achieve the desired line speed increases, many at grade pedestrian crossings needed to be replaced with footbridges or subways to comply with health and safety guidelines. Network Rail contracted the provision of new structures in Midlands Zone to Birse Rail Ltd via the Structures Framework Contract. When the CCRM Project is complete Birse will have installed 23 new footbridges and 3 new subways.

The subject of this case study will be Rangeway subway, which now carries a public footpath under the Derby to Birmingham line near Kingsbury in North Warwickshire. The subway consists of a 3 metre wide reinforced concrete box with integral wing walls and approach slab. It was constructed 55 metres from the railway prior to the embankment being excavated and it being slid into position using the Brambles system during an Outside Rules Of The Route (OROR) possession. The slide path crossed the route of a medium pressure oil pipeline from the nearby Kingsbury Oil Depot.

The case study will include the planning, design and construction aspects of the scheme. During the planning and design stages, possession and track removal/reinstatement requirements were established and Her Majesty's Railway Inspectorate (HMRI), Local Authority, oil pipeline owner's and Environment Agency requirements were all addressed. As the main possession approached a contractual issue with one of the pipelines threatened to compromise the project. Birse Rail's construction management team therefore revised their programme to ensure the changes were accommodated without comprising safety, quality, the environment or the OROR possession.