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KEYNOTE PAPERS

STRATEGIC RAIL MAINTENANCE BY GRINDING ON HIGH SPEED LINES

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Keywords: Rail maintenance, re-profiling, grinding, high-speed lines.

Rail grinding has a wide range of successful applications. Originally deployed to treat problems in the longitudinal plane, rail rectification has also become a routine remedy for deformation of the transverse rail profile. In addition, it is increasingly used today to combat deterioration of the rail surface and sub-surface.

High speed traffic requires particular rail maintenance. The interaction between wheel and rail profiles plays a determining role with regard to safe and smooth steering so the equivalent conicity must be maintained within tight limits. Furthermore, high traction forces increase surface stresses considerably as becomes apparent from the accelerated development of rolling contact fatigue problems such as headchecks and squats.

Rail maintenance on high-speed tracks starts usually with an initial grinding before opening the lines to commercial service. This action needs to be followed up with the highest precision and in a strategic way. This keeps the rails in service as long as possible and assures reasonable life-cycle-costs. This paper covers all relevant aspects while explaining the importance of strategic rail maintenance on high-speed lines.

TECHNICAL AND SUSTAINABILITY ASPECTS OF HIGH SPEED RAIL

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Keywords: High speed trains, energy consumption, load factor.

In addition to features of both train and route, the passenger load factor is the principal parameter which determines the energy consumed per passenger-kilometre by a high-speed train. The concepts of route ‘sinuosity’ and ‘equal energy time saving’ are introduced to facilitate comparisons with the energy consumed by other modes for the same mission. Energy calculations for the design of a new high speed train system in the UK, combined with information from a previously unpublished aircraft energy use database, have enabled comparisons of energy used and CO₂ emissions to be made. With some caveats, the superiority of high speed trains is confirmed.

THE TRACKBED ASSET: IMPLICATIONS FOR MAINTENANCE AND RENEWAL STRATEGIES

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Keywords: Trackbed, formation, investigation, design, ballast cleaning, Net Present Value.

Maintenance and renewal intervention of permanent way track assets including rail, sleepers and trackbed is typically triggered by exceedance of track quality limits, rough

ride reports or ‘surface’ track condition surveys (automated or manual). However research has suggested a significant proportion of track quality problems are sourced in the underlying trackbed (ie ballast, sub-ballast, drainage, and subgrade). By using trackbed condition on a supplementary basis to other asset condition data, engineering need of the railway can be better met, deterioration of track support layers can be predicted and maintenance and renewal decision making improved. Possible benefits include mitigation of track failure earlier in the assets lifecycle using cheaper interventions, reducing requirement for more capital intensive remedial schemes and whole life costs. Alternatively the impacts of not addressing trackbed failure mechanisms can be understood and the appropriate maintenance plans and budgets put in place.

To optimise future trackbed maintenance and renewal in terms of technique and intervention timing, a detailed understanding of its interdependence with trackbed, drainage condition and historic track quality deterioration is required. An in-depth knowledge is also required of trackbed failure mechanisms and their affects on track quality and component deterioration.

This paper presents lessons learnt from the UK and the possible cost benefits (based upon Discounted Cash Flow analysis) of performing various levels of Trackbed Investigation and Design (TBID) on a site and network level to infrastructure owners.

HIGH-SPEED RAIL GEOTECHNICAL ISSUES

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Keywords: High-speed, geotechnical engineering, critical speed, transitions, switch and crossings.

There are many geotechnical challenges with operating high-speed trains on ballast tracks. For example the issue of soft soil can lead to the development of critical speed issues due to Rayleigh wave or other dynamic track developments. The propagation of ground waves can lead to vibration of local buildings and degradation of the track structure. In order for high-speed lines to be economically viable the amount of time that the track is being maintained must be as low as possible. In particular critical infrastructure locations, such as switch & crossings, and transitions etc, must be designed such that routine maintenance is kept low. For ballast tracks this can represent real problems due to movement of the ballast particles and hence track geometry correction. In this paper, some of the geotechnical issues surrounding ballasted high-speed railway tracks are highlighted, both in terms of the subgrade and upper ballast structure. A method for

3D track reinforcement and stabilisation is discussed and where appropriate examples given of solution types.

**Theme 1:
Permanent Way, Rail
Maintenance, Signalling +
Electrification**

High Speed Rail

‘THE SKY IS THE LIMIT’ HIGH-SPEED LINE WUHAN- GUANGZHOU CHINA

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Keywords: High-speed line, slab track, supervision.

Author has been involved as Senior Supervision Engineer for track in section JL4 for the new high-speed line Wuhan-Guangzhou (WuGuang line) in China in 2008 and 2009. Section JL4 covers the southern part of 247 km. The main track and switch construction applied in JL4 is the Rheda 2000 system and some switches are equipped with the Bögl construction. The paper will deal with the following items:

- introduction and organization of the project
- transfer of slab track technology to China
- the slab track construction Rheda 2000
- logistics, in particular China’s manpower
- construction problems like tight schedule, amount of work and quality control
- defects during construction on different layers of the Rheda 2000 system
- supervision experience on site
- improvement proposals for design and the construction on site
- evaluation of the design
- evaluated view of the difference between ballast/ballastless track.
- conclusions WuGuang project.

The paper shows that China is able to reach a likely impossible goal for this project within time.

VIADUCTS FOR HIGH-SPEED RAILWAYS

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Keywords: High speed railway, design basis, dynamics of bridges, trough deck.

The design of viaducts for high-speed railways involves a dense interaction between different criteria. This is partly because of the constrained space available for structure when striving for a shallow visual depth. The design process is discussed through the headings of aspirations, context, criteria and opportunities. It is recognised that the structural analyses required for designing viaducts for high speed railways are much more extensive than those required for highway viaducts. For a major project many bridge designers would be required and, following current practice, it is likely that the time and resources available for design would be limited. Few would have the relevant experience. It is recommended that preliminary design studies should be undertaken at an early stage in a project. The results should be used firstly to review how well the operational requirements of the railway fit with beneficial structural forms to find the best mutual outcome for structure and operations. The final outcomes of the studies would be reported with the Design Basis so designers are given a feel for the implications of the detailed requirements. The studies would also explore less conventional but promising configurations such as the trough deck which a designer would not otherwise have time to consider.

VERTICAL STIFFNESS AS A DESIGN PARAMETER OF A TRANSVERSE SECTION IN HIGH SPEED LINES

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Keywords: Railway high speed lines, vertical stiffness, design.

The most used criteria in cross section design for the railway infrastructure, use parameters such as track elements (rail, sleepers, etc), traffic or subgrade bearing capacity. The track elements of high speed lines seems to be well defined due to the experience in this field. The traffic (i.e. the number and weight of trains axles) and speed, depend on the route layout and the line demand and they cannot be easily modified. The third point concerns the quality of the subgrade, which means taking into account the values of the CBR (California Bearing Ratio) test. This quality affects on the track behavior, i.e. on the deformation and settlement due to the passage of rail traffic. This is due to the relationship between the vertical track stiffness and the subgrade quality. In addition, other important issue, is that this deformation, affects directly on the dynamic vertical overloads and therefore on the deterioration of the track. Those reasons seem to justify the need of use the vertical stiffness as a new parameter for designing transverse section in railway lines. Since problems like track deformation and dynamic overloads becomes even more important in high speed lines, this paper deals with this problem and provides several graphs that can be used in the infrastructure design.

3D FE MODELLING OF GROUND DYNAMICS FOR HIGH-SPEED TRAINS

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Keywords: Finite Element; Ground Dynamics, high speed trains.

This work deals with the ground induced vibration due to a high speed train through 3D finite element (FE) modelling. It focuses particularly on the numerical investigation, for validation purposes, of the response of homogeneous single layer overlying bedrock subjected to a point load and the study of the railway track response at different train speeds in the sub-critical and super-critical ranges. The developed 3D FE model uses 20 noded brick elements for the track components for the sleepers, the ballast and the sub-grade. 3D beam-column elements are considered to describe the rail. The time integration is performed explicitly via mass lumping. The far field of the soil is truncated and absorbing boundary conditions are incorporated.

First numerical experiment in the case of a static point load acting on homogeneous half space is carried out and results for studying the vibration attenuation of the ground response when harmonic point loading is applied on the free surface of a single layer overlying bedrock are presented. The compression wave cut-off frequency is accurately estimated in terms of the frequency content, as theoretically predicted. Preliminary study are also conducted to show the effect of ground vibration when the train exceeds the Rayleigh ground wave speed.

DESIGN OF SINGLE-TRACK HIGH-SPEED LINES FOR RELIABLE OPERATION

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Keywords: High-speed rail, single-track, crossing loop, timetable supplement, capacity.

This article deals with homogeneous high-speed traffic on single-track lines and the time supplement needed in the timetable to manage crossings. Calculation of such supplements is an essential part of the estimation of achievable average speeds and travel times. Only cases with homogeneous traffic, high standard infrastructure and limited frequency of service are evaluated. The results show that a single-track high-speed line is a realistic alternative, provided that these requirements are met. The evaluation shows that three kinds of crossing loop are to be considered in further investigations:

- **Scheduled crossing loops with regular passenger stop.** These loops are most preferably designed with turnouts for 160 km/h and extended loop tracks of 1,500 m. This design minimizes the time supplement needed for the crossing.
- **Scheduled crossing loops without regular stop.** These loops need to be extended into partial double-tracks. A recommended length is 20,000 m. Turnout standard should be 160 km/h. A trapezoid design is preferable for a rhomboid.
- **Secondary crossing loops.** These loops are not planned to be used as scheduled crossing loops. They are rather reserve loops to be used in greatly delayed situations and for extra trains operated in rush-hour traffic. It is, however, important that also these loops also have a high standard, 160 km/h turnouts and

1,500 track length, since the uncertainty of future operation and timetable calls for timetable flexibility, i.e. a possibility to find alternative feasible timetable solutions than the one used to for the infrastructure design.

The results are a good base for further evaluation with studies of real alignment, loop locations etc.

ALTERNATIVE METHODS TO PREDICT GROUND BORNE VIBRATIONS ON STRUCTURES ON DIFFERENT SOILS

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Keywords: Ground borne vibrations, simulation, finite element method, finite difference time domain.

Analytical and finite element models are commonly used to investigate ground borne vibrations from high speed lines. This paper will examine the strengths and limitations of each type of model and discuss the possibility of an alternative solution, namely the use of a seismic 'finite difference time domain' (FDTD) technique. It will also present a FEM model that has been developed to benchmark a FDTD that is under construction.

RAIL TRACK ANALYSIS USING FINITE ELEMENT MODELLING TECHNIQUES

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Keywords: Finite element method, railtrack, rail, stress.

With the growth in both High Speed and Light Rail infrastructure projects worldwide there is a general requirement for accurate modelling of the interaction of the track with respect to any supporting bridge structures, and in particular, to ensure that any interaction between the track and the bridge as a result of temperature and train loading is within specified design limits. The passage of one or more trains crossing a rail bridge causes forces and moments to occur in the rails that, in turn, induce displacements in the supporting bridge deck, bearings and piers. Rail Track Analysis software, such as that developed for LUSAS [1], permits track/structure interaction analysis to be carried out to the International Union of Railways Code UIC 774-3 [2] for ballasted or unballasted tracks. It automatically builds models from data defined in Microsoft Excel spreadsheets and quickly produces results in spreadsheet or proprietary software formats to enable checking to specified design criteria.

FIELD MEASUREMENT AND PERFORMANCE EVALUATION OF HIGH-SPEED RAILWAY TURNOUT ON BALLASTED TRACK OF PASSENGER DEDICATED LINE

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Keywords: Passenger dedicated line, high-speed turnout, field measurement, lateral displacement, analysis, simulation.

Turnout status plays a great role on the running safety, speed, stability and comfort for the high-speed train. In order to learn the dynamic characteristics, evaluate the working performance and the effects of high-speed railway turnout while train running through, some field measurements are carried out on 60kg/m rail No.18 high-speed railway turnout on ballasted track of Hefei-Nanjing passenger dedicated railway line in China, such as track geometry investigation, wheel-set lateral displacement dynamic measurement and tongue rail height measurement etc. In this paper, the measurement devices are illustrated and the data gathered in-situ is analyzed. The track geometry data analysis shows that the track geometry status in turnout is controllable and also satisfied with the requirement of the maintenance regulation of permanent of way. The inspected lateral displacement data analysis shows that when the train runs through the turnout with high speed, lager lateral displacement will occur in tongue rail and crossing zone, the higher the speed, the larger the lateral displacement, and the maximum lateral displacement may be up to 5-6mm; The lateral displacement values in switch zone are larger than those in crossing zone.

CONTRIBUTING TO LOWER LIFE CYCLE COST OF HIGH SPEED LINES

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Keywords: Life Cycle Cost, Key Asset Design Life,
2nd Generation Slabtrack.

This paper considers the challenges and opportunities to optimise the Life Cycle Cost of High Speed Rail. It assumes a mix of ballasted and slabtrack within a High Speed Network. For the slabtrack sections tunnel, elevated and constructed sections the challenge is initial cost and speed of construction, the opportunity is in integrated design and 2nd Generation Slabtracks. For ballasted sections the paper proposes a ‘design rationale’ change for defined key assets making the design life of the trackform compatible with its importance to the rail system – Key Asset Track Structures. Use of sleeper pads and polyurethane injection are considered in ensuring the full required design life. The availability of Life Cycle Costing models is essential to ensuring track design offers the future rail infrastructure owner the best value in reliability and ongoing cost.

Theme 1: Permanent Way, Rail Maintenance, Signalling + Electrification

Railway Management + Operation

SPEED AND PRECISION IN RAILROAD BALLAST DELIVERY AND DUMPING SYSTEM: USING GATESYNC AUTOMATED TECHNOLOGY

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Keywords: Ballast, dumping, GateSync, profiling.

Although numerous ballast delivery solutions exist for the North American railroad industry, stressed budgets among the railroads during challenging economic times necessitates, the creation of more innovative solutions that would ensure sustainability of effective ballast maintenance programs. Georgetown Rail Equipment Company (GREX) has recently implemented among some US railroad companies, GateSync automated technology, as an efficient alternative solution to the current ballast delivery and dumping systems.

Combining the GateSync technology (synchronized ballast gate unloading system) with Solaris (automated, remote unloading hardware), the railroads are able to quickly and accurately deliver ballast exactly where they need it. Once a track survey to identify target areas and where rock should not be deposited (road crossings, bridges and switches) is completed, the data is downloaded into the GateSync system and the result is precision ballast delivery at speeds of up to 10 mph. By automating this process, fewer railroad personnel are needed for the same amount of work, implying that the overall safety of the entire operation is improved. Moreover, increased productivity and safety means improved operating costs to the railroads.

Despite the GateSync technology making significant in-roads into the

railroad industry, and continued positive impact on ballast delivery and maintenance practices across the customer-base, its potential is still relatively unknown. This paper therefore, presents the key features of the technology; the differences between GateSync capability versus other manual/automated ballast delivery practices currently in use and the level of accuracy and repeatability of GateSync dumping results against the customer 'No Dump Zone (NDZ)' requirements.

The paper concludes by outlining the planned technology improvements to ensure robustness of the solution, as well as indicating some of the customers currently using the GateSync technology in ballast dumping, to reduce overall system maintenance costs.

BY HOW MUCH AMOUNT OF TRACK MAINTENANCE WORKS COULD BE DECREASED?

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Keywords: Asset management, risk optimization, optimal maintenance plan, data modeling, track geometry, exceedances.

The total costs of rail infrastructure and its maintenance are very substantial and from a large part of total infrastructure expenditure. Any reduction of these costs has a significant impact on the overall efficiency and management of the infrastructure. It is therefore of high importance, to those responsible, to keep the condition of the permanent way at a given quality level to a minimum of total cost.

There are several drivers that make infrastructure planners to decrease amount

of maintenance works by postponing or dropping preventive maintenance as much as possible. These actions could ease the work schedule, decrease costs, and shorten the down-time of the network. However, less maintenance works also means higher risk of failure during the exploitation, and consequently higher project expenses due to the expected fines. Finding the optimal balance between these drivers is an ultimate goal toward a reliable infrastructure management.

ARCADIS' approach to solve the described challenge is to optimize overall costs of infrastructure projects by finding the optimal balance between maintenance costs and expectations of fines by varying the failure risk for each project variant and calculating the cost expectations. Behind the process is a multi dimensional behavioral model developed and build on both actual and history geometry measurements using digital signal processing and data mining methods.

It enables railway infrastructure companies, infra managers and contractors to define enhanced Maintenance and Renewal (M&R) plans expenditure and the financial consequences of those policies.

CRITICAL RAIL FAILURES AFTER 11 YEAR TRAFFIC AT LRT SYSTEM AND HOW DO WE COMBAT THE PROBLEMS FOR IMPROVED PASSENGER COMFORT

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Keywords: LRT, rail failures, RCF, rail grinding, noise.

Urban Rail systems have a lot of benefits for the public beside some bad effects, especially corrugation and rolling contact

fatigues (RCF) are very important for all of urban and commuter systems. At Izmir LRT we have continuous periodical checks against RCF's which are caused by rail-wheel interaction and contact stress. This article has studied a lot of rail surface failures that we call head checks, corrugations, squats which appears at IZMIR and combating strategies and tracking grinding methodology.

INVESTIGATING THE IMPACT OF TIMETABLE PROPERTIES ON DELAY PROPAGATION ON A DOUBLE-TRACK LINE USING EXTENSIVE SIMULATION

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Keywords: Train delay, railway operation, double-track, simulation, heterogeneity.

Today many railway lines are operated close to maximum capacity. A common question asked is: 'How is the quality of operation affected if one additional train/h is scheduled?' With the upcoming deregulation of operation, the necessity to be able to answer this question accurately increases when service operators that are denied train slots due to congestion demand a motivation.

The objective of this paper is to investigate how secondary delays on a congested double-track line depend on several parameters such as:

- number of trains/h
- timetable heterogeneity (speed difference)
- primary delay levels
- inter-station distance.

Each combination of settings of the parameters is investigated to capture possible interaction effects.

The infrastructure model consists of a fictitious double-track line with overtaking stations at regular intervals. A program that generates timetables and perturbation data according to specified input settings is developed. The output of the program is data files that can be read directly by the well-known simulation tool RailSys. This process makes it possible to simulate the hundreds of different timetables that are the result when the parameters investigated are varied. The outcome of the simulations is analysed to find the influence of the investigated parameters on the secondary delays.

INVESTIGATION OF THE INFLUENCE OF RAILWAY SYSTEM PARAMETERS ON TRACK CAPACITY

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Keywords: Track capacity, UIC (Fiche 405-1), track saturation ratio, capacity influence parameters.

The present study investigates the effect of various parameters of the track, the rolling stock and the operation and exploitation conditions on track capacity, calculated by the method proposed by the International Union of Railways (UIC), using an appropriate simulation model. Some of the parameters taken into consideration include the length of the critical track subsection, the average running time of passing trains, the level of service, the existence and positioning of an intermediate block signal within the critical track subsection, the degree of traffic uniformity etc. For all of the examined parameters, variation charts of track capacity and track saturation ratio were extracted, for both the cases of operation: track with one-way traffic

and track with bi-directional traffic. The analysis showed that the parameter that mostly affects track capacity is the level of service, expressed as the buffer time taken into consideration after each train's departure, in order to avoid additional delays. Also, the length of the critical track subsection and the average running time of passing trains have a significant impact on track capacity. Finally, it was proved that the existence of an intermediate block signal within the critical track subsection can lead to an increase of up to 43% in track capacity.

AUTOMATIC DATA COLLECTION AND ANALYSIS FOR RAILWAY INFRASTRUCTURE MAINTENANCE

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Keywords: Asset management, automatic inspection, condition-based maintenance management, decision support, planning, control.

Reducing the number of failures such as interruptions and speed restrictions is the current challenge for any railway. Moreover, when new types of traffic such as high speed as well as new asset materials are introduced is fundamental to assess with objective condition data any change in the railway infrastructure performances aimed to prevent failures occurrence and improve asset life cycles.

Condition monitoring technologies allow railways to collect many and different data, in many cases, more than what operators involved in condition based maintenance can process. Proper methods to collect and process data to provide efficient and effective responses to maintenance engineering departments are required.

New practices to assess railway infrastructure performances based on diagnostic as well as decision support technologies are being introduced at different railways. Any practice is depended on traffic type (heavy haul, freight, transit, traditional and high speed), type of assets, maintenance process in place and other aspects.

The paper will describe the main enabling practices involved in the collection and analysis of condition data for condition based and predictive maintenance; in particular it will illustrate how data can be used for both assessing the current asset condition and optimize maintenance.

APPLICATION OF A MODIFIED FUZZY-AHP METHODOLOGY TO RAILWAY RISK DECISION MAKING PROCESS

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Keywords: Risk assessment, decision making, Fuzzy-AHP, expert judgement, railway depot.

Railway risk assessment is a hierarchical process where risk information obtained at lower levels may be used for risk assessment at higher levels. Fuzzy analytical hierarchy process (Fuzzy-AHP) is widely used in risk decision making process to solve imprecise hierarchical problems where the risk data are incomplete or there is a high level of uncertainty involved in the risk data. However, when application of traditional fuzzy-AHP in risk decision making, the risk analysts often face the circumstances where huge pairwise comparison matrices have to be completed. Even if it is a single pairwise comparison matrix, it still requires $n(n-1)/2$ judgements at a level with n alternatives. Additionally, there may be a lack of

confidence that all comparisons associated with the system are completely justified in a rigorous way. This is particularly true when a complex railway system to be analysed or when subjective judgements should be involved. This paper presents a modified Fuzzy-AHP approach that employs fuzzy multiplicative consistency method for the establishment of pairwise comparison matrices in risk decision making analysis. The use of the proposed method yields a higher level of confidence that all of comparisons associated with the system are justified. Furthermore, the workload in determining the consistency of the judgements can be reduced significantly. A comparative case example on shunting at a railway depot is used to demonstrate the proposed methodology. The results indicate that by using the proposed method, risks associated with a railway system can be assessed effectively and efficiently, and more reliable and accurate results can be obtained.

A PROCEDURE FOR THE DYNAMIC ANALYSIS OF RAILWAY ACCIDENTS BY MEANS OF TRAIN MONITORING

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Keywords: Train accident, multibody software, dynamic analysis.

Railway accidents, although they are not as frequent as road accidents and the majority of them do not produce severe damages, some may have disastrous effects. The need for ascertaining their causes in order to clarify responsibilities

and achieve safer railway operations makes the investigation of such accidents a key matter for railway companies, the railway industry and governments. Even though the large variety of kinds of accidents and the disparity of circumstances in which they are caused leads to the unsuitability of coming up with general analysis procedures, for those railway accidents involving dynamic behaviour of train and tracks and their interaction a procedure that can be followed is presented. This procedure consists of a first stage of field measurements and a second stage of computer modelling and was set up as a result of the investigation of the railway accident which occurred in Valencia's underground on July 3rd 2006, in which a train went off the tracks and turned over. Its application to the accident allowed clarification of the causes and the discarding some of the initial hypothesis, achieving thus satisfactory results.

CALIBRATION OF SIMULATION MODEL ON THE SOUTHERN MAIN LINE IN SWEDEN

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Keywords: Railway operation, simulation, train delay.

Suitable analysis methods are needed for evaluation of future timetable scenarios, both in short term operational planning and for strategic planning with a longer time horizon. One method is to use simulation software which makes it possible to model quite large networks. The Swedish Transport Administration is in a process where the aim is to start using simulation software RailSys as their primary tool for timetable planning. This will at first be applied for long term strategic planning

with the possibility to also use it in operational planning further on.

The main focus in this paper is to estimate primary run time extensions from registered data. Ideally these should only represent primary causes, e.g. decreased vehicle performance, variation in driver behavior or infrastructure malfunctions. These extensions are important in order to make simulations more realistic. Different reduction levels of registered data are tested in order to estimate primary run time extensions. Registered data used are absolute values without distinction between primary and secondary causes. Calibration and validation simulations are done on the Southern main line in Sweden where the mix of high and low speed trains is substantial.

EFFECT OF OUTSOURCING COST OF RAILWAY TRACK MAINTENANCE AND REPAIR

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Keywords: Maintenance cost, outsourcing, railway privatization, track maintenance and repair.

Nowadays in all parts of the world, majority of railways are conventional ballasted track systems, which their maintenance and renewal impose high costs to railway companies. For solving this problem, lots of methods and strategies have been supposed and evaluated by railway infrastructure experts that improvements in track maintenance management and privatization of track maintenance projects are among them. Iranian railway network is ballasted system and costs of maintenance, repair and renewal of this network allocate considerable amount of annual budget of the railway. In the past decades, all parts of Iranian railway were managed by government and all of staffs working in the

field of construction, maintenance, repair and renovation of tracks were employees of government. In recent decade in order to modify the quality of track maintenance and repair operation and decrease the current costs of railway, maintenance and renovation of majority of Iranian's railway track network have been outsourced. In this paper the effects of outsourcing in track maintenance and repair costs will be documented.

A METHODOLOGY FOR ROLLING STOCK RAM TARGET SETTING DEMONSTRATION

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Keywords: Rolling stock RAM, RAM target, service profile, service performance objectives.

The purpose of rolling stock RAM (reliability, availability and maintainability) analysis is to set up targets in order to improve service performance of rolling stock to the required level, for example, quality of service, performance of reliability and safety, and availability of equipment etc. Therefore, the quantitative targets of rolling stock RAM have to take service performance requirement into consideration and the performance of rolling stock achieved must precisely demonstrate the objective evidences that consist with service performance objectives. Although some work has been conducted in this field, no formal methodologies have been developed and applied to a stable environment in the railway industry. This paper presents a methodology for setting the quantitative RAM targets based on service performance objectives, ie reliability, availability and maintainability of rolling stock, service

profile and maintenance resource. A case example on high speed train is used to illustrate the proposed RAM specification process.

OBTAINING A RAILWAY TRACK MAINTENANCE STRATEGY VIA APPLYING OPTIMAL MAINTENANCE SCHEDULING MODEL APPROACH

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Keywords: Track irregularity, track maintenance schedule, maintenance cost, optimal maintenance strategy, risk cost.

This paper aims at investigating an optimal railway track maintenance strategy for minimizing the maintenance cost defined as the sum of track tamping cost and risk cost for derailment accident. Firstly, we develop an all-integer linear programming model for obtaining an optimal railway track maintenance schedule. Model results give the relation between tamping cost and quality level of track irregularities. We formulate a mathematical model to estimate the tamping cost through the quality level of track irregularities. We also develop a mathematical model to estimate the risk cost for derailment accident caused by large track irregularities while considering the magnitude of accident from the viewpoint of both casualty and probability of occurrence. Finally, by applying these models to actual railway data, we obtain the optimal maintenance strategy including range of surface irregularities to maintain. Then, we confirm that our models are effective and useful enough to optimize maintenance strategy.

**Theme 1:
Permanent Way, Rail
Maintenance, Signalling +
Electrification**

Trackbed

MECHANICAL CHARACTERISATION OF THE BLANKET LAYER IN THE OLD RAILWAYS TRACKBEDS

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Keywords: Old railways, trackbed, blanket.

In the track bed of the old railways platform in France, a blanket layer was created mainly by interpenetration of sub-grade soil into the ballast layer under train actions. The accumulated permanent deformation of this layer is caused by the repeated loading at the railways platform through progressive shear failure. In the present work, a large scale triaxial cell (soil specimen having 300 mm in diameter and 600 mm in height) is used to study the mechanical behaviour of this coarse soil (the maximal diameter of grains is 60 mm). The soil was compacted to a dry density of 2.01 Mg/m³ and three values of initial degree of saturation were tested (32, 48 and 100%). Compression triaxial tests were performed under constant-water content conditions in order to determine the shear strength parameters (friction angle and cohesion) and the Young's modulus. Subsequently, cyclic triaxial tests were performed within one million of cycles. The experimental results evidenced the effect of water content on the mechanical behaviour of this coarse soil. First the shear strength of the soil compacted at 4% of water content is 18%

higher than that at 6% and at saturated state. Secondly, the soil behaviour under cyclic loading is depending on the moisture content. A permanent axial strain of 0.4% water found after one million of cycle for the test at water content of 4% while it was 1.4% for the water content of 6%. For soil specimen at saturated state, failure was even observed. Finally, an existing model usually used to predict the permanent strain of coarse soil under cyclic loading was applied to fit the experimental results. The effects of water content on the parameters of this model were discussed.

OFOTBANEN, HEAVY HAUL LINE FOR 30 – 31 TONS AXLE LOADS

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Keywords: Track construction, vehicle characteristics, track forces, track shift incidents, maintenance efforts.

Ofofbanen is the Norwegian part of the Iron Ore Line in Norway and Sweden for heavy haul freight of 30-31 tons axle load. This paper presents information about construction and geometry of the track of this line (Norwegian part only) and describes the experiences of heavy haul and other traffic on Ofofbanen. The characteristics of the railway vehicles (wagons, locomotives) will be described shortly. The track forces are presented due to measurements and calculations. The maintenance efforts in order to provide for an operating line will be dealt with. The paper is not applicable or valid for the Swedish part of the line.

Some special peculiarities observed will be discussed.

SOUNDNESS EVALUATION OF SLAB TRACK BY IMPACT ELASTIC WAVE TESTING

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Keywords: Soundness evaluation, impact elastic wave testing, slab track, resonant frequency and concrete slab.

In general, slab track maintenance has been performed based on visual inspections. However, as it is considered that visual inspections involve subjective elements of an examiner, more objective and quantitative evaluation method is required. In this paper, we evaluated the bending stiffness of cracked concrete slab by its resonant frequency which is measured by impact elastic wave testing with an impulse hammer. Furthermore, we conducted an additional test for cracked concrete slab whose cracks were intentionally prepared. Finally, we have confirmed through measurement of resonant frequency that the bending stiffness of concrete slab decreased with the progression of fracture.

LIFE ASSESSMENT OF SLABTRACKS

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Keywords: Slabtrack, concrete, life assessment.

The majority of slab tracks in the UK were constructed within tunnels in the 1970's and 80's, using the shallow construction

depth to allow the required overhead line clearances for the electrification of the lines. Though currently requiring relatively low levels of running maintenance, the majority of sites are now entering the second half of their designed life. In light of the cost to the network of unplanned track closures and delays, a maintenance strategy needs to be planned in advance of failures, factoring in the cost of repairs against the cost of compensation for delays. Alterations to the rail network including increased axle loadings, longer trains and increased journey frequency have lead to a further requirement for assessments.

In order to assess the slab track residual life, knowledge of the material strength and thickness as well as train axle load is needed. The maximum tensile stress within the concrete slab is calculated under the axle loading by modelling the structure as a multi-layer elastic system and the ratio of the calculated stress to the strength of the concrete is used to determine the number of load applications before concrete cracking, employing an appropriate fatigue model.

A combination of non intrusive and intrusive investigations are undertaken to provide an assessment of the slab construction and condition while minimising the damage to the structure. This data is then used to model the predicted life of the slab based upon a range of influencing factors. The life provided is indicative only and relates to a conservative estimate of the onset of concrete failures. These concrete failures typically represent the onset of cracking which as designed, remains constrained by internal reinforcement, allowing continued running on the line, but of significance is that they indicate the point in the slabs life where maintenance levels will increase. In the areas of limited access where most of the slabs are situated, this is a vital consideration in the cost strategy for the line.

CYCLIC LOADING TEST WITH FULL-SCALE MODEL FOR PRE-STRESSED BALLAST TRACK

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Keywords: Ballast track, settlement countermeasure, earthquake resistance, model test, and cyclic loading.

It has been required to take a drastic measure to decrease maintenance work for the typical ballasted tracks for the Shinkansen, which has high-density transportation. In addition, improvement of the earthquake resistance for the existing ballast track is an important subject in Japan.

For the above-mentioned reason, the authors are under development of Pre-stressed Ballast track termed PSB-track, which has the least degree of track settlement and has large earthquake resistance. The sleepers of the PSB-track are constantly pulled down against ballast by the tie rods fixed to the anchors laid under roadbed; therefore, confining pressure acts on the ballast constantly. When the confining pressure acts on the ballast, both of its shear strength and stiffness largely increase; accordingly, track settlement decreases, and lateral resistance increases. Consequently, it is highly likely that the cost for track maintenance decreases and the earthquake resistance increases.

In this paper, the authors performed the cyclic loading test with a full-scale model for the aforementioned PSB-track, and thereby its restraint effect on the track settlement was demonstrated.

LONG-TERM MONITORING OF ANTIVIBRATION MATS FROM RUBBER RECYCLATE

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Keywords: Antivibration mat, long-term monitoring, rubber recycle, vibration propagation, substructure, bearing capacity.

Since the year 2000 antivibration mats produced from rubber recycle have started to be embedded in the sleeper subsoil in selected sections of railway tracks in the Czech Republic. The quality of carriage track is continuously monitored and samples of mats are taken for verification of key elastic and material characteristics. In the article, experience with the present usage of antivibration mats for the limitation of vibration propagation into the surroundings of railway tracks is summarized. Special attention is focused on factors that significantly influence the quality of antivibration mats in dependence on time.

STUDY ON THE TIME-DEPENDENCY IN DEFORMATION PROPERTIES OF UNIFORMLY-GRADED CRUSHED GRAVELS USED AS RAILROAD BALLAST.

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Keywords: Time-dependency, uniformly-graded gravels, triaxial compression test, ageing effect, viscous effect.

In this study, triaxial compression tests with monotonic loading (ML) on uniformly-graded crushed gravel have been carried out under various loading conditions, including constant strain-rate ($\dot{\epsilon}_0$), 10 times $\dot{\epsilon}_0$, 100 times $\dot{\epsilon}_0$, incremental strain-rate changes during loading with and without creep stages, to consider time dependency in strength and deformation characteristics of this material. Based on test results, it was found that the influence of viscous effect to the strength of uniformly-graded crushed gravel was not observable. Therefore the time-dependency effect on the strength properties is considered to be minimal. Noticeable influence of viscous effect was observed on the deformation characteristics of uniformly-graded crushed gravel, which reveal that the time-dependency has considerable effect on the deformation properties of these materials. Moreover, the effect is rather more evident in materials with cyclic loading history. The influence of loading rate and loading acceleration on $\epsilon_{vol} - \epsilon_a$ behavior was not observed, which transpires that time-dependency has minimal effect on dilatancy characteristics of these materials.

RESTORATION TECHNIQUES FOR CONCRETE TRACK SETTLEMENT

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Keywords: Concrete track, settlement, restoration.

The intention of this study is develop the pressurized rapid-hardening cement grouting (PRCG) method to restore the subsided concrete track without harmful effect to train operation. This method consist of special types of materials (very quick hardening and middle hardening mortar), compact grouting equipment and a construction process. This method is demonstrated by a field test. Also, this paper proposes the technique of impact echo and the FRACTAL (Flexural-Rigidity Assessment of Concrete Tracks by Anti-Symmetric Lamb Waves) method. Impact echo is used to evaluate the filling capacity of the materials and FRACTAL is used to evaluate a weak stiffness underneath the trackbed.

3D-DEM SIMULATION ABOUT DYNAMIC BEHAVIORS OF BALLASTED TRACK UNDER IMPACT LOADING

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Keyword: Ballasted track, impact loading, dynamic response, residual settlement, 3D-DEM, discrete ballasted track model, clump-spheres model, image-based model.

A series of 3D-DEM simulation is carried out using a 3D discrete element ballasted track model to clarify the mechanism of the differential settlement formation caused by

impact loadings. We imposed 2 cases of simplified loading data – with and without impact loading – on the totally identical ballasted track model. Simulation results show that the residual displacement of the sleeper and the ballast grains increases under loadings ‘with impact loadings’ compared with that under loadings ‘without impact loadings’. Then we can observe that the number of contact points between ballast grains suddenly decreases just after impact loadings because of excited ballast grains behaviour. It suggests that the impact loadings increase both grains dynamic behaviour and residual displacement which causes the differential settlement.

DAMPING AND MECHANICAL PROPERTIES OF DRY ASPHALT RUBBER FOR SUB-BALLAST LAYERS

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Keywords: Damping, stiffness, dry asphalt rubber, sub-ballast layers.

The passage of railway lines through a town or near built-up areas poses serious environmental problems such as noise and vibration. Consequently railway companies have shown an increasing interest in developing new materials with high mechanical and environmental performance.

This paper presents the results of an experimental research on the potential application of Dry Asphalt Rubber (DAR) in sub-ballast layers by measuring its damping and mechanical properties. An experimental survey based on four point bending and Marshall tests was carried to measure the stiffness modulus and damping

ratio both of a standard bituminous mixture and of dry asphalt rubber mixture with a rubber content equal to 1,5%. The experimental results were compared and a numerical analysis by means of a 2D lumped mass model was developed. It was found that DAR is a material with good stiffness and high damping ratio, making it a very attractive material for the sub-ballast in order to reduce the ground borne vibrations caused by train.

STUDIES ON IMPROVEMENT OF TC-TYPE LOW-MAINTENANCE TRACK

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Keywords: TC-type low-maintenance track, drainage equipment, round bar clip type fastening.

East Japan Railway Company (JR East) developed TC-type low-maintenance track to reduce maintenance work and costs. TC-type low-maintenance track was first laid on Yamanote line in 1998, and is now used along 200 km of track in the Tokyo metropolitan area. Its structure incorporates 400 mm-wide prestressed concrete sleepers with cemented ballast 200 mm thick supporting the sleepers from beneath. Ten years and more since TC-type low-maintenance track was first laid, the frequency of most maintenance work was decreased. However, the track has subsided in places where the roadbed was weak or groundwater level was high. We planned to drain the groundwater to lower the groundwater level to 500 mm below the roadbed surface, as a result, the track irregularity was improved. Also, in a

tight curve section as less than 400 meters curve radius, some broken round bar clips were found. We investigated the cause of breakage, as a result, concluded that another bar clips seem to be suit to the condition of tight curve section of TC-Type Low-maintenance track. This paper presents the results of improvements on TC-type low-maintenance track.

A SYNTHETIC REPLACEMENT FOR SAND-BLANKETS: TO PREVENT PUMPING FAILURE

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Keywords: Geosynthetic, filter, railway, trackbed.

This paper describes the development process undertaken to produce a lightweight, geosynthetic filter to replace a sand-blanket used within trackbed as a method of preventing and solving the subgrade erosion problem known as ‘pumping’. The issue of ‘pumping failure’ is discussed, with an explanation of the cause and effect, as well as the various methods that have been tried as a means of tackling the problem.

The development program is then explained, including the design and construction of a full scale trackbed test facility that simulates real conditions in the harshest of environments. There is some discussion relating to the project deliverables and methodology used to test and prove the functionality of proposed materials. The materials selection process is discussed, with some explanation of the way in which each component within the geocomposite was selected and evaluated.

The paper then goes on to discuss the evaluation of durability in relation to design life assessment, both in terms of mechanical and chemical performance, the importance of selecting the correct polymer and the

mechanisms of degradation.

Finally, the movement from laboratory trials to full scale use is explained, with some evaluation of the field use and the scope for further development.

A CASE STUDY IN CONSTRUCTION OPTIMISATION FOR SUB-BALLAST LAYER

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Keywords: Design optimisation, construction quality, sub-ballast, in-situ testing.

The performance requirements of modern railway tracks demand a proper design in order to meet safety and passenger comfort standards, taking into account the optimization of the infrastructure life cycle.

The sub-ballast layer, namely the characteristics of the materials used, plays a fundamental role in the track behaviour. However the requirements established for these materials are not consensual worldwide. Very stringent requirements have been adopted in many countries, making it difficult to find adequate materials.

The studies presented herein were performed during the construction of an upgraded section of the Portuguese Lisbon – Algarve link, designed for a maximum speed of 220 km/h. During the construction it was difficult to obtain the desired quantity of granite material for the 30 cm thick sub-ballast layer in order to fulfil the applicable standards and the design requirements and still respect the contract deadline. To

overcome this problem, the contractor suggested an alternative structural solution that considered the replacement of the bottom 15 cm of the granite material sub-ballast layer by limestone material.

Therefore, it was necessary to study the feasibility of the alternative solution in order to assure the construction quality. Several studies were developed, such as laboratory characterisation and *in situ* testing.

The studies performed and the results presented in this paper show that the implemented alternative was adequate and complied with the quality requirements specified in the contract in a more economic way.

EXPERIMENTAL INVESTIGATION ON DRY ASPHALT RUBBER FOR SUBBALLAST

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Keywords: Ballasted rail track, dry asphalt rubber, mix design.

The asphalt rubber mixes have a wide application field in the railroad and road superstructures because of their technical and environmental properties. While in many countries the wet process is often used to make bituminous mixtures, the dry process doesn't have the same degree of application even though a larger recycling of waste tires rubber is allowed than the dry process.

This paper focuses on the mix-design of the Dry Asphalt Rubber (DAR) for subballast of the railroad superstructure in order to define a sound laboratory procedure of mix-design with reference to Marshall test and Superpave Gyration

Compactor (SGC) test. The comparison between Marshall test and SGC test highlights the need to introduce a specific method for measuring the real volumetric properties of the analyzed DAR mixes.

NDT TO DETERMINE STIFFNESS & FOULING OF BALLAST & TRACKBED ON HIGH SPEED RAIL ALIGNMENTS

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Keywords: Railway maintenance, ballast, spent, fouling, analysis, testing, impulse, response.

The increase in freight and passenger rail travel has driven demand for more efficient and rapid investigation of railway trackbed ballast. One of the current approaches to evaluating the stiffness of railway ballast is to use a Falling Weight Deflectometer. Whilst this is very effective, it requires the rails to be unclipped from the ties – thus, it is very intrusive and expensive.

This paper explores the option of using a frequency response function (FRF) generated by using a 12lb instrumented hammer to excite railway trackbed ballast composed of variously fouled ballast, with response measured using a geophone. Finally, the FRF is successfully correlated with the assessed Fouling Index of the ballast.

CORRELATION BETWEEN BEARING CAPACITY (K_{30}) AND ELASTIC MODULUS (E_s) USING THE LFWD TEST

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Keywords: Light falling weight deflectometer, plate load test, dynamic load.

An evaluation of the Light Falling Weight Deflectometer (LFWD) device to reliably measure the in-situ elastic modulus of pavement layers and subgrades is presented in this paper. For this purpose, field tests were conducted on selected railway sections from different project in Korea. All sections were tested using the LFWD in companion with other standard tests including the Plate Load Test (PLT) and Cyclic Plate Load Test (CPLT) that were used as reference measurements. Regression analyses were conducted on determine the best correlations between the elastic modulus obtained from LFWD and those obtained from PLT and CPLT test. Good correlations were obtained, which demonstrated that LFWD can be a promising device for in situ characterizing of railway layers and subgrade.

CHARACTERISTICS OF EARTH PRESSURES FOR THE BALLASTED TRACK UNDER MOVING WHEEL LOADING

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Keywords: Moving wheel load, settlement, earth pressure, ballasted track, railroad.

In this paper, we have compared and analyzed the difference of the earth

pressure driven from the two different loading conditions; fixed-point loading condition and moving wheel loading condition from the model test. Traditional experiments were performed on a fixed-point and it tends to cause incorrect results since a real train traffic load is exerted through moving wheels. So this paper compares the difference of the earth pressure characteristics when it's differently measured by fixed-point loading or moving-wheel loading fixed condition. Test result shows that the earth pressure from moving wheel loading is contrary to that of static loading. The Earth pressure at the central part under the condition of static loading is smaller varying from 27.7 kPa to 178 kPa while the earth pressures at the end-side under the condition of moving wheel loading varies from 30 kPa to 130 kPa. However, the earth pressures at the end-side were bigger when it's measured under the condition of moving wheel loading.

LIFE EXTENSION OF RAILWAY TRACK SYSTEMS

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Keywords: Railway maintenance, vacuum, ballast, Railvac, life extension, track.

This paper describes the latest developments in the processes for track life extension particularly the use of the 'Railvac' Swedish ballast removal machine. The principal author has included the historical context of the research including the work undertaken previously where he acted as the major driver behind the work under

industrial conditions. A number of case studies and their specific solutions are identified and reviewed.

LARGE SCALE GPR EXPERIMENTS ON RAILWAY BALLAST

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Keywords: Railway maintenance, gpr, ballast, testing, spent, analysis.

The overall aim of this project was to relate Ground Penetrating Radar (GPR) to ballast fouling. Earlier research at the University of Edinburgh has enabled researchers worldwide to characterise ballast using impulse radar (GPR) based upon the relative electrical permittivity or dielectric constant. In this paper, a series of GPR experiments, following on from previous laboratory experiments, were undertaken on the University of Edinburgh trackbed using a range of bowtie antennas from 500MHz to 2.6GHz. The key innovation reported is the use of scatter analyses of the GPR waveforms, featuring area, axis crossing and inflexion point analyses. These scatter analyses were then used to predict the Ionescu Fouling Index. A correlation coefficient greater than 0.9 was obtained by using a 500MHz bowtie antenna in the parallel orientation in conjunction with a scan area analysis.

This paper will also outline the recent work of other researchers and the detailed experimental programme at the University of Edinburgh.

**Theme 1:
Permanent Way, Rail
Maintenance, Signalling +
Electrification**

Rail

OUR COMMITMENT IN REALIZING EFFICIENT AND EFFECTIVE RAIL GRINDING

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Keywords: Rail grinding, trace generated by rail grinding, pattern of rail grinding.

Currently, JR East is committed to realizing efficient and effective rail grinding, with specific objectives of extending service life of rails, preventing flaws on rail surface. However, we face challenges concerning the rolling noise generated by the rail surface after grinding and the flaws on rail gauge corners.

For reducing noise after rail grinding, we developed new grinding procedures which include the modification of grind stones, adjustment of the speed of the grinding car, and the addition of a “finishing pass”. By adopting these standards, we have succeeded in resolving noticeable traces and in mitigating noise.

In Japan, we could grind only the top surface of rail by the regulatory guidance. But, due to transport service disorders caused by broken rail stemming from fatigue of the gauge corner part, we focused on securer grinding that prevent flaws and mitigate fatigue on gauge corners. After confirming that our methods did not lead to flange climbing, we expanded the range of grinding to the top surface of rail.

We now have started the implementation of these methods of rail grinding. We are committed to reviewing the result of it with a view to realizing the efficient and effective designing of rail grinding.

STRESSES ANALYSIS ON A RAIL PART

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Keywords: Railway track, field strain survey, rail stresses.

The *Estrada de Ferro Vitória Minas* (EFVM) is one of the main railways from Brazil. It transports freight trains of ore, 220 waggons each. These waggons have 2 boogies of 2 axles each and 32 metric tons on metre gauge. Elastic strains were measured on a special part of this railway due to these waggons. The measurements were obtained by dynamic deflectometer installed on a main line of this railway, near Ipatinga, a city from Minas Gerais, one of Brazil states. This track was equipped to obtain stresses under an equal repeated static load. A simulation of the stresses was made under critical strain by *Ferrovias 1.0* software. It was also made an evaluation of unequal results from neighbour sleepers taking in comparison two equipped parts of this railway, one, with compacted ballast and no compaction to the other. The results were strain limited, avoiding breakage or damage to the studied rails. This work analyses these measurements focusing on the improvement of track quality.

INFRASTRUCTURAL, AUDIBLE AND FINANCIAL BENEFITS OF TOP OF RAIL FRICTION MODIFIER ON UK RAILWAY NETWORK

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Keywords: RCF, rail wear, lubrication, friction modifier.

Curved track is acutely vulnerable to rail wear including RCF, cracks, pitting, cold metal flow and corrugation, the costs involved in re-railing and grinding can be in the order of tens of thousands of pounds *per annum, per curve*. RCF and related phenomena are primarily caused by shear stress at the contact patch; the result of lateral and longitudinal creep generated by steering and high coefficient of friction, stick slip at the wheel rail interface causes excessive squeal noise. Curves are also susceptible to wear at the gauge corner; lubricating to alleviate wear by reducing the coefficient of friction at the gauge face of high rails is a technique successfully employed across the railway network in the UK. Friction modifiers are now being used to manage stick slip and shear stress at the wheel rail interface that causes damage to the rail and excess noise on the low rail of curves. Reduction of rail damage phenomena and squeal at notorious curves has been observed and resulted in estimated savings of around £16,000 *per annum, year on year* at a case study curve. This cost is quantified from the extension of life seen in the rail, the reduced requirements for grinding and the investment in the equipment for friction modifier at the site.

CONTINUOUS NON-DESTRUCTIVE MONITORING OF IN-SITU FISHPLATED JOINTS USING OPTICAL FIBRE SENSORS

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Keywords: Fishplate, optical fibre sensor, fibre Bragg grating, intelligent infrastructure.

A novel optical fibre sensor based technique for monitoring the critical, maintenance-intensive sub-components of tram and light rail systems is presented in this paper. An instrumented fishplate joint was placed in a tram network and the signals generated by a multiplexed array of optical fibre strain sensors attached to the fishplates were recorded during its interaction with trams crossing at in-service speeds of between 5.1 and 6.7 m/s. Torque settings from 150 to 320 Nm were applied to the bolts of the fishplate joint during the trial and initial analysis of the data captured during the test is presented.

**Theme 1:
Permanent Way, Rail
Maintenance, Signalling +
Electrification**

Rail-Wheel Interaction

DEFINITIONS AND QUANTIFICATIONS OF RESILIENT MAT STIFFNESS PARAMETERS: AN INVESTIGATIVE LOOK INTO KEY ASPECTS OF THE NEW DIN STANDARD 45673 PART 5 AND PART 7

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Keywords: Track resilience, resilient mats, stiffness quantification, DIN 45673.

The precise definitions and concomitant quantification methods of resilient mat stiffness parameters are ostensibly simple and uncomplicated. After all, how many resilient mat stiffness parameters can be meaningfully defined from a track engineering point of view and how much influence can stiffness definitions and concomitant quantification methods exert on the predicted degree of Insertion Loss – let alone the real-world degree of vibration isolation performance? Paraphrasing the famous dictum ‘a rose is a rose is a rose’, one may be lead to think that ‘stiffness is stiffness is stiffness’ thereby giving mat stiffness an aura of straightforwardness with little to debate once a rated static or dynamic stiffness value has been taken from the resilient mat manufacturer’s product data sheet and having only a modest influence on the functional performance of the resilient mat.

However, as the fundamental working principle behind the use of mats in resiliently supported tracks for ground-borne mitigation purposes lies in the construction of a mass-spring-damper system with the aim of introducing a low ‘first’ resonance frequency of the overall track structure the theoretical stiffness along with the real-world stiffness of the mat plays a crucial role. Introducing novel

yet practical concepts is precisely the reason why the new and encompassing standards DIN 45673 part 5 and part 7 are deemed by many track engineering professionals to become essential for everyone interested in the stiffness characterisation of resilient mats regardless of whether one is active on the German rail market or not.

This paper accordingly takes an in-depth look at the various stiffness definitions along with practical aspects of working with the new DIN Standard 45673 part 5 (dealing with resilient mats for the substructure in ballasted tracks) and part 7 (dealing with resilient mats for the substructure in floating slab tracks). The basis for this paper can be found in full in the standards DIN 45673 part 5 and part 7 which may be purchased directly from the publishing arm of DIN Deutsches Institut für Normung e.V, that is, the Beuth Verlag in Berlin. The aim of this paper, therefore, is not to replicate the content therein but is rather to provide for an introduction to the various key concepts from DIN 45673 part 5 and part 7 taking a theoretical as well as a practical track engineering and acoustics engineering point of view.

INFLUENCE OF COVERED MILEAGE ON TRAM WHEEL WEAR

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Keywords: Tram wheel, rim wear, covered mileage.

Tram wheel wear plays an important role in maintenance of every tram system. Zagreb Municipal Transit System (ZET) has recently acquired 140 new low-floor trams (CROTRAM TMK 2200) that started

their operation and is about to acquire additional 60 low-floor trams (CROTRAM TMK 2300). In order to predict time for wheel re-profiling and eventually wheel replacement extensive investigation of wheel rim wear had to be made. Precisely predicted behaviour of rim wear, dependent on covered mileage, gives valuable information to maintenance department in order to anticipate and schedule wheel rim re-profiling and eventually order new wheel rims for replacement, thus achieving uninterrupted operation of a tram.

This paper describes an investigation of wheel rim wear on several trams (TMK 2200) operating on Zagreb tram network. Trams were selected depending on the covered mileage including, completely new trams (5,103 km) up to 5 years old trams (98,977 km). Using precise digital measuring device ‘GRAW Wheel profile gauge A-B’, specially redesigned for this purpose (in order to fit the tight clearance space under a low-floor tram), precise wheel profiles were acquired and investigated. Analysis of the measurement results correlated wheel rim wear with covered mileage of a tram as well as with the position of a wheel on a tram (front, middle or rear bogie).

THREE DIMENSIONAL VEHICLE-TRACK-BRIDGE INTERACTION ANALYSIS BY THE VECTOR FORM INTRINSIC FINITE ELEMENT METHOD

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Keywords: Vehicle-track-bridge interaction (VTBI), vector form intrinsic finite element (VFIFE), large rotation, derailment.

This paper presents the analysis of the three dimensional vehicle-track-bridge interaction (VTBI) behaviors by a new computational method called the Vector Form Intrinsic Finite Element (VFIFE) method that is capable to do the nonlinear large deformation analysis of structures. The particle dynamics algorithm within the VFIFE method does not require solving any VTBI parameters iteratively. Hence, it is capable to investigate versatile of nonlinear dynamic problems like the motion behaviors of carriages derailment failure with the large deformation and the dynamics of the vehicle-track-bridge system due to earthquake excitations. Numerical examples demonstrate that the analysis method proposed in this study can effectively and accurately analyze the nonlinear, dynamic behaviors of the vehicle-track-bridge system.

Theme 1: Permanent Way, Rail Maintenance, Signalling + Electrification

Metro + Light Rail Systems

NECESSITY FOR URBAN RAILWAY STANDARDS

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Keywords: Urban railway, standards, track.

Track alignment, track irregularities are defined in railway standards primarily from mainlines networks. A proposal for defining standards specific to urban railway was carried out and is presented in this paper.

The subjects dealt with in the present document, are leading to conclusions on track geometry, track roughness and vibration mitigation.

Complete models including track and vehicles were setup allowing for simulations taking into account the actual conditions of the track.

The track geometry was studied in relation with its mechanical response and the resulting forces and stresses undergone. Following measurements of track gauge, vertical alignment, and cant and horizontal alignment, an approach based on 95% compliance can be applied and conclude that a track is compliant with the EN 13231-1 standard acceptance tolerances for these track parameters.

The results of the track geometry study can be proposed as a contribution for the development of urban track standards.

The approach pertaining to vibration mitigation has to consider the whole vibration transmission path and to be adapted to the vehicle that will be operated.

And the vibration performance of a transportation system must be defined in relation to its compliance with a level of vibration measured at building locations

and not by empirical rules based on outdated data.

The measurements made on many other sites for several tram designs and manufacturers are correlating this observation:

- a very high performance system (floating slab) is rarely required
- a continuously supported rail system is sufficient in many cases.

TRAM TRACK IN CITY CENTERS MINIMUM HINDRANCE, MAXIMUM PERFORMANCE

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Keywords: Tramway track, design, installation, vibration insulation, slab track.

In a large number of cities across the globe, tramways are essential arteries for commercial, social and cultural activities, in particular in city centers. Tramway transportation is an easily accessible and environment friendly transport modality compared to cars and busses and offers quite large transport capacity volumes. Most modern middle to large sized cities (500.000 and more inhabitants) are having a tramway network, are building, upgrading, rehabilitating or planning it in order to meet today's demands on transport and quality of life.

The design of tramway track as well as installation, renewal and replacement requires typical points of attention. Two of these points are noise and vibration insulation and speed of installation. These points form the starting points for the recent developments of prefab slab track (Urban Slab Track) installation and vibration insulation slab track mats (TRACKELAST STM product range). Both developments

have come together in a recent, very successful project in the Swedish capital of Stockholm. This paper will present a number of typical issues in development, preparation and execution of this project as well as the performance since it has been taken into service.

CONVERTING AN ABANDONED RAILWAY INTO AN AFFORDABLE TRAMWAY – THE PRESTON GUILD LINE.

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Keywords: Railway, tramway, tracks, power supply, street interfaces, conversion, adaptation.

Reusing old urban railways as a modern tramway is a temptation in traffic congested towns. If the alignment serves the right places and a viable patronage can be attracted, these can make the basis of a high speed light rail or tram system. Such lines will normally require links on local roads to reach strategic traffic objectives.

This paper sets out some of the engineering issues of converting an old railway into a tramway, rather than running trams on a railway. This starts with the tracks, the off and on street interfaces, the OHL and power supply, and operational matters impacting on alignment and design etc.

FAST TRACKING RAIL VEHICLE DESIGN

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Keywords: Rail, bombardier, carbody, bogie, HyperWorks, FE, CAE.

Bombardier Transportation UK offers one of the most comprehensive and diverse rail vehicle portfolios in the world. The strategy is one of continuous development that provides the most effective and costefficient rail solutions for today and the future. A key ingredient is the use of Altair HyperWorks enterprise computer aided engineering (CAE) solution. Altair's technology is now present at every stage of the design process and has increased the efficiency of the product development process. The paper details how Altair tools have been used to generate Finite Element (FE) models of carbodies, bogies and secondary structures in reduced time scales. Significant weight and cost savings are achieved through structural optimisation of components such as large steel castings, aluminium extrusions and steel fabricated structures which are subjected to linear static, fatigue and abuse loading. Automated post processing facilitates the interpretation of results and the writing of detailed official reports.

MTR TRACKFORM UPGRADING PROGRAMME

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Keywords: Metro, track, upgrading.

The MTR Corporation is widely recognised as the provider of a world-class public transport service that consistently achieves the highest international standards in safety, reliability, and efficiency. As one of the world's most densely-utilised urban railways, four million passenger trips are made on the network on a normal weekday.

The MTR's first three metro lines were built between the mid-1970s and mid-1980s, with tracks running mainly through underground tunnels at below sea level. The track support structure used was continuous plinth made of reinforced concrete. However, over the years, these track support structures have experienced spalling in the reinforced concrete and occurrences of corrosion in the rails, requiring high levels of maintenance.

To address these issues, the MTR Corporation launched a long term plan to upgrade its continuous plinth trackform with the objectives of improving asset performance, extending asset life, achieving lower life-cycle costs and enabling future conversion of the existing BS11-90A rail with the heavier 60E1 (or UIC60) rail which is the standard for all new lines.

This work can be conducted only in non-traffic hours as extended possessions and service shutdowns are unacceptable on a network that is so heavily used every day. Both the technical designs and construction methods have been continuously refined to ensure high quality and efficient renewal.

This paper explains how MTR is

achieving the objectives in its trackform upgrade programme as part of its overall asset management strategy.

TRACKWORK RAM STUDY FOR A METRO PROJECT NEW DEVELOPMENTS

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Keywords: Trackwork, RAM, failure, life cycles.

At Railway Engineering 2009, a paper from the same author was presented. That paper was aimed to describe what the main aspects of a trackwork RAM study are. The work carried out since that presentation has originated new views on the subject. The track is a complex system and the complexity is justified by the fact that the track has something of a civil structure and something of a mechanical plant. A correct approach should take account of both natures of it. The frequency of renewal of track components is an essential datum of a service management but this datum is not the result of a deterministic analysis. The expected lifetime of track components is not only dependant on the component itself and its design and manufacturing. Other influencing factors are the environment and the capabilities of the management. In a metro line these factors are, if possible, strengthened because of the limited accessibility of the line. The quality of the design is certified by the care provided in simplifying the likely influence of these factors. This paper take again some of the considerations of the 2009 paper and expand them stressing the effects of a good management, of a well-designed accessibility and of all what can be foreseen during the design process.

**Theme 1:
Permanent Way,
Rail Maintenance, Signalling +
Electrification**

Track Geometry, Sleepers/Ties

ALIGNMENT DESIGN FOR THE DOUBLE TRACKING HALLSBERG – DEGERÖN

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Keywords: Alignment, CEN, European standards,
EN 13803-1.

The present paper is focused on alignment design for the upgrading (double tracking) of a mixed traffic line in Sweden. Important aspects to consider are locations of crossovers and passing loops, requirements regarding permissible speeds, borders for the available terrain corridor and track standards defining the limits for the track alignment design parameters. These requirements will normally allow for either an almost infinite number of different track layouts, or will not allow for any solution at all.

When there do exist possible solutions, additional criteria should be used for the selection of the ‘best’ solution, among the infinite number.

These additional criteria explain why track layouts differ substantially between different countries, even though track standards are fairly similar.

INTRODUCTION OF NEW RIDING QUALITY MANAGEMENT SYSTEM

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Keywords: Shinkansen, riding comfort, track
deflection management.

JR East has actively addressed the improvement of riding comfort for Shinkansen by adopting a track deflection management system based on 40m chord track deflection and vehicle movement acceleration.

As a result of above, the track condition has been improved and the high level of riding comfort could be achieved. In the future, such management of track deflection for riding comfort will become important more and more, because we are planning to increase the operating speed of Shinkansen up to 320km/h with new model of train.

However it was concerned that the cost of maintenance would be hiked under higher speed operation if we carry out existing track management method with tighter targets suite to 320 km/h operation. Therefore we decided to apply the new track management system for riding comfort for further improvement of riding comfort, accuracy of monitoring track, and cost-efficiency.

In this presentation, the author will explain ‘the new track management system for riding comfort’ which was comprehensively consolidated with further improvement of the accuracy of monitoring track, immediate action in the case of occurrence of excessive figure, the tools to find out the cause of deterioration of riding comfort and so on.

In addition to that, the author will introduce the new method for further comfortable riding in JR East in near future.

HIGH ATTENUATION SLEEPER – VALIDATION ON SITE

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Keywords: Vibration mitigation, booted sleeper.

The environmental considerations resulting from the operation of urban railway, especially noise and vibration have become

a crucial subject for people living alongside lines or above underground lines.

ALSTOM Transport and SATEBA have developed a system, which provide a high performance in mitigating vibrations.

The development of this system up to the lab-testing phase was presented during last Railway Engineering in 2009.

In order to validate the performance in terms of vibration mitigation but also construction and maintenance, a 60m long test track was built on the Railway Testing Centre (CEF) in Valenciennes (France).

Measurements were done by D2S International under circulation and this was an opportunity to determine the performance in insertion gain but also to measure displacements and stresses.

The results are presented and comparison could be drawn between simulations and measurements on site.

THE DYNAMIC BEHAVIOUR OF THE TRACK LENGTH PROVIDED WITH Y SLEEPERS

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Keywords: Track length, sleepers, dynamic behaviour.

The paper deals with the analysis of the behaviour of the track length provided with Y-type sleepers under the dynamic load by sets of carriages on the Czech railway lines. The fundamental aim of the measurement of Y-type sleepers in the rail was the verification of the transfer of vertical and transverse loads to the top ballast and the interconnected shifts of the track length. Simultaneously, the

analysis of the transfer of vibrations to the track length and to the railway bed was made. The global behaviour of track skeleton with application Y-type sleeper was compared with standard construction transverse concrete sleepers. The paper also includes the description and application of the methods of measuring and the selection of a suitable mathematical apparatus for the evaluation of the measured parameters. The methods both in the time and especially in the frequency regions were utilized. The measuring carried out offered data for mathematical modelling. The conclusion comprises the evaluation and recommendations for the practice.

FIELD INVESTIGATION ON DISTRIBUTION OF CONTACT PRESSURE BETWEEN SLEEPER AND SATURATED BALLAST WITH FLOWING SAND

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Keywords: Sleeper-ballast contact pressure, railway in sandy areas, ballast fouling.

For analysis and design of concrete sleeper, it is necessary to have a complete and comprehensive vision of the loads transferred from other components of track into the sleeper. In this case, two topics should be investigated: Share of load for the sleeper under the wheel and status of contact pressure distribution underneath the sleeper. About these two issues, several factors are involved, including: Sleeper type (material and physical characteristics), sleeper spacing, rail-sleeper fastening system, track maintenance conditions and conditions of the sleeper bed. Sleeper bed conditions, is one of the most important and influential factors in the amount and distribution status of sleeper loads. This

issue is important, because the track modulus is dependent to the sleeper bed conditions. Change in track modulus, makes many changes in the applied loads and their reactions. Desert regions are one of the critical areas in this field that in these areas, flowing sand causing the ballast layer to be filled with fine sandy aggregate and consequently by the change in track modulus, amount and distribution status of applied loads to the sleeper change as undesirable.

In this paper, results of the field investigations about the effects of increasing amounts of flowing sand into the sleeper applied loads and changes occurring in the pressure distribution under the sleeper are presented. This work has been done with some load cells insertion underneath the sleeper and the results are compared with results of field tests relating to non-sandy areas.

**Theme 1:
Permanent Way,
Rail Maintenance, Signalling +
Electrification**

Points + Switches

INVESTIGATION OF FAILURE STATISTICS FOR SWITCHES AND CROSSINGS IN THE UK

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Keywords: Failure statistics, switches and crossings, rail damage characteristics.

Switches and crossings (S&Cs) failure statistics for the UK rail industry are investigated for the various types of S&C in the network with varying geometry, switch length and allowable speed limit. The analysis is based on recorded delay and failure rectification costs for a single (financial) year. The overall cumulative delay cost and the failure cost per unit have been included in the investigation. Wear has been shown to be the common damage type in all lengths of S&C in terms of delays and rectifications costs, since one of the rectification procedures for such failure type is replacement of the asset. Mid speed switches, such as C length and D length switches, have high industrial relevance due to the high failure delay costs. The normalised delay per total population showed a highest delay cost for the high speed G+ length switch.

INFLUENCE OF USP ON DYNAMIC LOAD IN TURNOUT

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Keywords: Railway superstructure, under sleeper pads, turnout, crossing, dynamic analysis, rail deflection.

Two trial track sections with under sleeper pads (USP) have been constructed in the Czech Republic three years ago. One of these sections is focused on an USP application in a turnout (1:12-500-I). The design of USP arrangement in the turnout was solved by the help of a finite element method (FEM) model. The calculations were performed for static load with an aim to design homogenous vertical stiffness along the turnout length as well as in the part immediately behind the turnout. USPs were designed on all turnout bearers. Two USPs with different bedding modulus have been applied on single bearers in the area of crossing and behind the long bearers. The turnout with USPs has been operating since 2008.

The next step of research is an implementation of dynamic load into a model analysis. It was also investigated a cheaper variant of USP's arrangement in which under sleeper pads are designed only for select bearers with the same effectivity to dynamic effects reduce. This paper is focused on a design of under sleeper pads only for a few bearers under a crossing.

Calculations have been performed for dynamic loads. Dynamic forces have been evaluated by two ways – the first one is an analytical method; the second one is a combination of analytical calculations and a FEM model. The dynamic forces and the corresponding vertical deflections have been determined for rails passing through a crossing. The calculations for both solution methods have been accomplished for the J60-1:12-500-I turnout for these arrangements:

- bearers without under sleeper pads
- bearers with bedding modulus $C_{stat} = 0,100 \text{ N.mm}^{-3}$
- bearers with bedding modulus $C_{stat} = 0,250 \text{ N.mm}^{-3}$
- bearers with bedding modulus $C_{stat} = 0,300 \text{ N.mm}^{-3}$
- one bearer with USP under the nose of the crossing (USP bedding modulus of $0,100 \text{ N.mm}^{-3}$, $0,250 \text{ N.mm}^{-3}$ and $0,300 \text{ N.mm}^{-3}$)
- three bearers with USP under the nose of the crossing (USP bedding modulus of $0,100 \text{ N.mm}^{-3}$, $0,250 \text{ N.mm}^{-3}$ a $0,300 \text{ N.mm}^{-3}$)
- five bearers with USP under the nose of the crossing (USP bedding modulus of $0,100 \text{ N.mm}^{-3}$, $0,250 \text{ N.mm}^{-3}$ a $0,300 \text{ N.mm}^{-3}$).

DEVELOPING THE HIGH FIXITY CONDITION USING 3-D POLYMER GEOCOMPOSITES

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Keywords: Gauge clearance, polyurethane, XiTRACK, lateral loading, absolute clearance.

There are many sites in the railway environment when gauge clearance problems become an issue. An example is the lateral drift of the railway track towards station walls/platforms. Solution of these problems can be difficult due to the track geometry and confinement issues and hence a technique that can rapidly capture the lateral track geometry to provide a very robust level of track fixity is extremely desirable. In this paper the application of the 3-dimensional polymer/ballast reinforcement technique XiTRACK to achieve this robust track fixity level is shown through experimental tests on full scale GeoComposite beams. The tests show that high stiffness and strength is achievable and hence the development of a new category for track fixity using polyurethane GeoComposites is possible. The paper concludes by showing the application of the technology to real sites on the UK railway, namely the East London Line.

EVALUATION OF RUNNING STABILITY OF TILTING TRAIN ON EXISTING CIRCULAR CURVE

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Keywords: Wheel, load, tilting, train.

The safety of tilting train running on curved track is, in general, evaluated with a derailment coefficient calculated by the ratio of wheel load and lateral force, Particularly on curve, the wheel load and lateral force on rail may cause trackbed to be deformed, depending on their intensity, and moreover, often result in critical accident such as derailment. This study hence was intended to identify the cause of wheel load and lateral force so as to suggest the allowable wheel load reduction rate, lateral force limit and derailment coefficient, thereby quantitatively evaluating the operational safety of tilting train.

This study therefore was aimed to analyze the wheel load and lateral force occurred during tilting train's operation on circular curve in such a way of comparing with traditional trains, by axle and speed, evaluate the operational safety of tilting train.

EVALUATION OF TRACK PERFORMANCE WHILE ACCELERATING ON EXISTING CURVE SECTION (R500)

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Keywords: Tilting, wheel load, lateral pressure, running stability.

A tilting train which has been in trial operation on existing railway is able to run faster than existing trains from the curve line depending on the status of approximately 10-30% is possible while running the curve section. However the train is affected by increasing centrifugal force at curved section which is conveyed to the wheel and rail, resulting in increased lateral pressure on outer side and derailment coefficient, while wheel unloading tends to increase on inner side, Curve Track ballast is needed for a quantitative review.

Thus in this study, it proposed to establish the criteria of allowable limit in wheel load, lateral pressure and derailment coefficient to ensure the tilting train in trial operation will run the curve section (R500) safely as well as to evaluate the bearing force of the track and the operational stability on curve section, by operation speed and kind, in preparation for launching revenue operation of tilting train so as to quantitatively assess the wheel load and lateral pressure, and wheel unloading and derailment coefficient were developed for comparing with the reference, thereby determining the operational stability of the tilting train.

**Theme 1:
Permanent Way,
Rail Maintenance, Signalling +
Electrification**

Electrification + Signalling

SYSTEMS INTEGRATION ON THE EAST LONDON LINE

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Keywords: European Interoperability Directives, signalling, traction power.

The East London Line Project is part of a plan to deliver a new round-London train service by upgrading and integrating various existing sections of both National Rail and London Underground's old infrastructure to form a seamless new service delivering up to 24 trains per hour per direction. This paper focuses on Phase 1 of the system (£1.4 billion) which was opened for service two months early in April 2010, and the challenges of integrating what is a relatively small section of railway into the National system and meeting the requirements of the European Interoperability Directives.

The paper will address some of the challenges of integrating the system to meet the needs of a 21st century railway in the centre of a major city within the confines of what was originally a 19th century Victorian steam railway. The signalling and traction power systems for the railway will be described and particular integration challenges which were successfully overcome on programme will be discussed, particularly obtaining secure sources of power for the system and rail arcing problems at the interface with the Network Rail system. The latter is ongoing at this time and the presentation will cover the progress made in its resolution.

TRACTION POWER MODELLING FOR POWER SUPPLY AND NETWORK ENHANCEMENTS OF DC METRO SYSTEMS

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Keywords: Traction power, modelling, substation, loading, OLE, regenerative braking.

Understanding the demands of a metro system on its existing power supply has taken great precedence in recent years. In addition, optimising historical metro networks to comply with new standards and to support introduction of modern rolling stock is proving to be a significant undertaking technically and financially.

In this paper, experiences of the authors in modelling various DC metro systems and the challenges met are presented. VISION[®]/OSLO[®] traction power simulation software has been used to model existing configurations of power supplies in metro systems and to make recommendations based on peak demand loading conditions.

The software provides analysis of the multi-train movement model and the traction power model interaction. Substation loading characteristics of instantaneous and RMS currents are post processed to study the demand on the Overhead Contact System. Innovative feeding arrangements to improve system loop resistance are analysed through simulation. Peak and average power loading characteristics of the substation are analysed in comparison with IEC standards. Energy calculations for the entire DC traction network are prepared to estimate improvements to system efficiency due to future timetabling with rolling stock having regenerative braking capabilities and to understand inherent system losses.

COST EFFECTIVE EARTHING SYSTEM FOR RAILWAY STATIONS

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Keywords: Earthing, grid mat, earth mat.

Most major railway projects are run by Project Managers who have a Civil and Structural (C&S) background. One of the main elements to railway station designs is the earthing system (ES), which must be designed and installed during the Civil and Structural designs stages to the Project, in order to save on cost and rework. Often, the earthing system design is considered much later in the Project by the Electrical Design Engineers by which time the structural foundation is in the process of being built. Therefore, Electrical Design Engineers employ commercially off the shelf (COTS) earthing system components.

This paper sets out the integration of the earthing system into the C&S designs and has been applied to the Crossrail project. The key approach is the integration of various engineering disciplines that would require the co-ordination and integration between the Geotechnical, Civil and Structural, Traction Power, Architecture and M&E designers to the railway project; with the technical inputs from the EMC and Traction Power consultant for the designs to the earthing system for the railway station. The work presented in this paper is confined to the earthing system design and the resistance.

OBJECTIVE TESTING PROCEDURES FOR DIRECT-ACTING DC TRACTION SUPPLY PROTECTION

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Keywords: Testing, calibration, supply protection, DC traction.

When calibrating most instruments there is an implicit assumption that the calibration represents a forecast; measured parameters will remain reasonably constant over a period of time. A bench-type DMM, for example, will normally remain within calibration for about 1 year and a properly-loaded resistive shunt of good quality will remain accurate for many years. Compare however the calibration process for the direct-acting overload (DAOL) on a traction supply circuit breaker (TSCB) with that for a simple electronic measurement device used in a laboratory. Whereas the measurement and indication processes for an electronic instrument are comparatively benign, a direct-acting over-load release (DAOL) clearly impacts significant energy into its mechanism. Although it is reasonable to assume that a shunt or digital meter, for instance, will (a) show similar behaviour to an identical device and (b) remain stable over an extended sequence of measurements, such assumptions are not always valid in the case of switchgear. In fact, measuring the DAOL in large switchgear fleets has shown significant differences between specimens in three main areas.

This paper is intended to explain and justify the level of testing required to provide confidence in the behaviour of the direct acting release on a traction supply circuit breaker. In fact, the core considerations apply to any system producing stochastic

variation in its output. With or without an assumption of stability, the stochastic component places limits on the credibility of an output forecast and this restraint can be used to determine objectively the amount of testing required to provide a given level of confidence in a system.

MAGNETIC FIELD VISUALIZATION FOR CROSSRAIL 25-0-25 KV AUTOTRANSFORMER TRACTION POWER SYSTEM

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Keywords: Magnetic field, EMF Directive, magnetic flux density, health effects.

There is general public concern about the potential health hazard caused by magnetic fields including those produced by the railway environment. Researches carried out by ICNIRP (International Commission on Non-Ionising Radiation Protection) reveal that prolonged exposure to time-varying magnetic fields could increase the risk of cancer.

New-built high performance AC railway systems operate with high capacity services (eg 24 trains per hour per direction, each train rated at 5.5MW and each train carrying 1500 passengers). It is essential to quantify the magnetic field levels to ensure the safety of passengers and workers.

New legislation and EMF Directive will be introduced by the HSE (Health and Safety Executive) in 2012, to impose legal obligations on employers to conduct risk assessments and electromagnetic field calculations, to ensure occupational exposure to magnetic fields is within the permissible limit.

This paper describes a comprehensive case study carried out by Mott MacDonald

for Crossrail to evaluate the worst case magnetic flux density produced by Crossrail's 25-0-25 kV AT traction power system. MATLAB and Simulink/SimPower have been used to aid the production of high resolution 2D magnetic field images for passenger stations, shafts, portals and tunnel sections of Crossrail Central Section to demonstrate compliance with the EMF Directive standard.

INVESTIGATION OF ARCING ACROSS INSULATED RAIL (BLOCK) JOINTS AT INTERFACE BETWEEN NEW AND EXISTING DC TRACTION POWER SYSTEMS

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Keywords: Traction, power, arcing.

Arcing has been occurring during the passage of new Electric Multiple Units (EMUs) across insulated rail (block) joints at the interface between the separate traction power return systems of a new DC third rail electrified railway and an existing established DC electrified railway. These systems are separated by a long (conductor rail) section gap, with the new system designed for high levels of running rail to earth resistivity. Results of a detailed technical investigation undertaken to understand the phenomena, consider and eliminate possible causes, and propose potential solutions for further development are presented. The investigation comprised a detailed review of designed and constructed traction power systems, and predictive modelling of stray leakage current flow. In addition, detailed examination in conjunction with the train manufacturer of arcing taking place on particular wheelsets

in relation to EMU traction equipment behaviour during passage through the gap and EMU bonding arrangements. Extensive visual observations, high speed video photography, and transient voltage measurements with simultaneous on-board train monitoring provided further insight. The probable cause was stray leakage current flow between traction power systems via EMU wheelsets, considered to be exacerbated by EMU traction current when coasting not employed. A range of solutions is identified, including snubber and switching arrangements, and an update on recent developments (and of further planned testing) presented.

EARTHING AND BONDING OF 25-0-25 KV AUTOTRANSFORMER TRACTION POWER SYSTEM IN A HIGH CAPACITY UNDERGROUND RAILWAY SYSTEM

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Keywords: Multiconductor transmission line model, interference, autotransformer traction power system, circuit model, ATP/EMTP.

Crossrail has adopted a 25-0-25 kV AT traction power system for the Central Section, to provide power for the high frequency train services, where each train is rated at 5.5 MW and each train carries around 1,500 passengers. There are traction and non-traction systems running in parallel inside the tunnel which may interfere with each other through conductive, inductive and capacitive coupling.

This paper describes a detailed Case Study of the earthing and bonding of the traction system to ensure that the entire system meets the earthing and bonding railway standards to ensure passenger safety.

The study recommends the crucial earth mat values for traction substations, passenger stations, shafts and portals, to demonstrate compliance with railway standards.

THE STUTTGART SIGNAL BOX SIMULATOR: A UNIQUE TOOL TO PLAN, TRAIN, AND OPTIMIZE TRAIN PROTECTION SYSTEMS

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Keywords: Light rail operation, infrastructure planning, signalling, train protection system, training, simulation.

SSB runs the Stuttgart light rail network, which has achieved the status of Germany's most metro-like LRT system. It makes use of train control and train protection systems, which require skilled staff to operate them. To train its signalmen, SSB uses a simulator to reproduce conditions at its live signal boxes. This tool allows the simulation of various signalling technologies, as well as interaction between local signal boxes and the control centre. It also enables SSB to create new signalling layouts *ad hoc* and to test them under realistic conditions.

Of all German metro and LRT operators, SSB makes the most use of its signal box simulator, making SSB's experience valuable for other operators of metro or suburban rail systems. This lecture will give an overview on SSB's approach towards, and experience in, signalling simulation and optimization over the past ten years.

RIGID CONDUCTOR BAR FOR 25-0-25 KV AUTOTRANSFORMER TRACTION POWER SYSTEM

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Keywords: Rigid conductor bar, autotransformer
traction power system.

Crossrail has adopted a 25-0-25 kV AC AT traction power system for the Crossrail Central Section (CCS), to provide power to 24 trains per hour per direction, with each train rated at 5.5 MW and each train carrying around 1,500 passengers. High power and high frequency trains require the support of high capacity traction transformers at the feeder stations as well as high current carrying overhead line equipment (OLE) system.

This paper describes in detail the proposed use of Rigid Overhead Conductor (ROC) for the contact line for the OLE system for use in the Crossrail sub-surface sections. This arrangement is adopted for both its mechanical and electrical characteristics.

The ROC is an aluminium extrusion, with a typical cross sectional area of 2,200 mm², which combined with a conventional copper contact wire provides the conductive path for the +25 kV, without the need for a parallel feeder cable to support the high currents being employed along the Crossrail route.

The use of the ROC arrangement reduces space requirements, negates the requirement for tensioning equipment, reduces installation cost within the tunnel, provides ease of sectioning within restricted environments and sectioning by ROC allows for section breaks to be located

close to the station platforms without compromising safety.

Theme 2: Railway Structures + Earthworks

Railway Tunnels

APPLICATION OF THE SAFETY IN RAILWAY TUNNELS TSI FOR GB TUNNELS

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Keywords: Safety, railway tunnels, technical specification for interoperability.

The safety requirements for railway tunnels are mandated for routes on the Trans European Network (TENs routes) through the implementation of the Safety in Railway Tunnels (SRT) Technical Specification for Interoperability (TSI). For non-TENs routes, tunnel safety requirements in GB are set out in Railway Group Standards (RGSs) including GI/RT7019, 'Safety in Railway Tunnels – Requirements for Lighting'.

To date, no new tunnel projects have been formally declared to require compliance with the SRT TSI or the RGS, but the Crossrail and Thameslink projects, will comply with the TSI, to the extent that is possible.

This paper will explain the legislative context for the TSI, describe the current situation regarding the provision of standards for safety in railway tunnels, consider the experience of the Crossrail and Thameslink projects in applying the SRT TSI, and identify some options for improvement of standards in this area.

RAMS PROCESS FOR THE AUTHORISATION OF COMMERCIAL OPERATION THROUGH THE LÖTSCHBERG BASE TUNNEL

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Keywords: Rail, Lötschberg Base Tunnel, reliability, availability, maintainability, safety, functional safety, safety case, EN 50126, EN 50128, EN 50129, EN 50388, fault tree analysis, failure mode & effects analysis, quantitative risk analysis.

The Lötschberg Base Tunnel is a 34.6 km long railway tunnel on the BLS Lötschbergbahn's Lötschberg Line cutting through the Swiss Alps some 400 m below the existing Lötschberg Tunnel. It accommodates passenger and freight trains and runs between Frutigen, Bern and Raron, Valais. Breakthrough was in April 2005 and construction ended in 2006. The opening ceremony was in June 2007. Full scale operation began in December 2007.

A comprehensive proof of safety and fitness for purpose was required to obtain the authorisation for commercial operation. A multi-disciplinary working group was in charge of planning and implementing the RAMS (reliability, availability, maintainability and safety) process in accordance with standard EN 50126-1. The main benefit results from the combined analysis of technical systems and of the planned procedures for operation, emergencies and maintenance. This paper describes the processes applied on this major project that lead to a successful and timely 'certificate of operation'.

Theme 2: Railway Structures + Earthworks

Railway Bridges

RISK-BASED DESIGN OF STRUCTURES FOR IMPACT FROM RAILWAY VEHICLES

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Keywords: Derailment, impact force, risk assessment.

The design of structures spanning adjacent to and above the track to resist impact forces from derailed trains, can sometimes be problematic, particularly where it is not possible to comply with the prescriptive requirements set out in the relevant standards. In such cases it is necessary to balance the risks associated with the likelihood of collapse of the structure following derailment, with the costs associated with the provision of works to mitigate the consequences of such an event. Eurocode BS EN 1991-1-7, makes provision for minimum resistance levels to impact but recognises that it is not always possible to achieve even these minimum levels, and that in some circumstances the minimum resistance levels may not be sufficient. Where the minimum resistance levels cannot be achieved or are insufficient, it is necessary to undertake a risk assessment to demonstrate that the adopted design solution has reduced the risks to a level that is 'as low as reasonably practicable' (ALARP). This paper will examine the design provisions in the relevant standards, consider the relationship between speed and the resulting impact force, demonstrate the application of the risk assessment methodology contained within UIC 777-2R and discusses more recent risk assessment developments at RSSB..

RESONANCE OF RAILWAY BRIDGE UNDER MOVING TRAINLOAD CONSIDERING THE EFFECT OF VEHICLE MASS

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Keywords: Railway bridge, dynamic response, resonance, moving mass, critical speed.

The dynamic characteristics in the railway bridge response to trainload excitation are complicated due to the involvement of the moving mass as well as the moving loads. Numerous studies have been carried out in the past dealing with the dynamic response of the railway bridges under a variety of parameter combinations. However, the effect of the moving mass on the bridge response is much less explored. This paper presents a combined theoretical and numerical study on the bridge resonance under moving trainloads, with a particular attention on the influence of the moving mass. For the idealised single carriage scenario, an effective natural frequency coefficient is proposed for the evaluation of the critical speed. For the bridge response under multiple carriages, a resonance severity indicator (the Z-factor) is developed for the assessment of the resonance effect when the loads move at a resonance speed. Numerical results demonstrate that the proposed methods are effective for the determination of the critical speed and the resonance effects, including the situations where a significant carriage mass is incorporated.

Theme 2: Railway Structures + Earthworks

Railway Earthworks

THE EFFECTS OF RAILWAY TRAFFIC ON EMBANKMENT STABILITY

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Keywords: Embankments, railway traffic loading, clay fill, plasticity.

Most railway embankments in the UK were built in the Victorian era and are of end-tipped construction using materials (usually cohesive) excavated from adjacent cuttings, resulting in a clod-and-matrix structure. Historically there has been a lack in understanding of the mechanical behaviour of such railway embankments. In the past ten years there has been an increase in embankment damage on the UK railway network, sometimes resulting in failure. This increase in damage has been accompanied by an increase in railway traffic loading due to higher axle loads and increased train speed. Additionally, over the next decade railway traffic in the UK, particularly freight, is forecast to grow considerably. Consequently, there is a need to improve the understanding of how increases in railway traffic loading may influence the mechanical behaviour of railway embankments and thus track performance.

The Rail Safety and Standards Board in conjunction with Network Rail is currently undertaking a programme of applied research into this topic. To date case records of recent embankment failures have been reviewed, recent/proposed changes in railway traffic loading considered and an

embankment vulnerability classification compiled for the UK rail network. This paper summarises the work done to date, the conclusions drawn and proposals for future work.

VOLUMETRIC IMAGING OF EARTH EMBANKMENT INTERNAL STRUCTURE AND MOISTURE MOVEMENT AS A TOOL FOR CONDITION MONITORING

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Keywords: Monitoring, geophysical imaging, resistivity, moisture content.

Transport earthworks, such as embankments, can be vulnerable to instability triggered by sustained wetting or drying events. The resilience of earth structures to these climatic stresses, particularly in the case of old waterway and railway embankments, can be difficult to determine due to the complexity of fill materials and the limitations of current approaches to characterisation and monitoring. For example, remote observation of change in surface morphology generally indicates late-stage failure, whilst point sensors provide insufficient spatial sampling density to adequately characterise, and therefore monitor, highly heterogeneous subsurface conditions.

Recent developments in geoelectrical imaging technology now enable full 3D characterisation and monitoring of earth structures to reveal compositional and moisture related variability. Here we describe a study in which automated time-lapse electrical resistivity tomography (ALERT) monitoring technology has been installed on a section of Victorian

embankment on the Great Central Railway (Nottingham). Through establishing geophysical-geotechnical property relationships by laboratory testing, electrical resistivity tomography (ERT) monitoring has been used to characterise the internal structure of the embankment, and image moisture content changes and wetting front development at a high spatial resolution. These preliminary results indicate that ERT has the potential to identify structures and processes related to instability at an early stage in their development.

APPROACH OF EAST JAPAN RAILWAY UNDER-TRACK SURVEY

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Keywords: Cave-in, roadbed, ground penetrating radar.

For the safe operation of trains, it is very important to prevent track settlement caused by cave-in of roadbed. Though there are many factors that cause cave-in, the most common phenomena are damaged pipe culvert and insufficient compacting at bridge approach. To detect a void under the track beforehand, East Japan Railway Company (JR East) has been developing effective ground-penetrating radars since 1991. Now, we operate two kinds of ground-penetrating radar devices, called 'UTRAS' and 'Portable UTRAS'. The UTRAS is a hi-rail vehicle with three radars

which can collect data simultaneously within and outside of the rails. The Portable UTRAS is a trolley with a single radar and easily to placed on and removed from rails at any spot. They are mostly used to survey voids above pipe culverts and near bridge approaches. Since 2010, we started developing the next UTRAS model. More effective detection capability and fast survey speed are required to survey all ground structure sections in JR East. We are developing a new antenna arrangements in labo tests.

EMBANKMENT STIFFNESS CHARACTERISATION USING MULTI-CHANNEL ANALYSIS OF SURFACE WAVE & CONTINUOUS SURFACE WAVE METHODS

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Keywords: Stiffness, surface wave, embankments.

The material and properties comprising the subgrade provide the most significant control on trackbed stiffness and thus, on rail performance. While standard industry tests such as the falling weight deflectometer provide large strain information relating to the stiffness profiles along the line, they provide no indication of the stiffness variation with depth. However, multichannel analysis of surface waves (MASW) and continuous surface wave (CSW) surveys can be quickly mobilised to characterise the lateral variation of shear modulus with depth along the line. Both methods utilise a geophone array to record surface wave motion through the

embankment. The CSW method uses a source that vibrates at a series of single frequencies, while the MASW methods can use an impulsive source. In both cases, small-strain, stiffness-depth profiles can be generated via simple inversion of the wave phase velocity-frequency dispersion curves. 2D sections of the stiffness variation along a Victorian railway embankment are derived using both methods and interpreted in relation to engineering properties of the composite fill. This paper evaluates each technique and provides guidelines for good practice.

UPLIFT AND SETTLEMENT TEST DEPENDING ON SHAPE OF JACKING-PIPE UNDER THE RAILWAY

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Keywords: Settlement, uplift, jacking, underpass.

Ground settlement or heaving displacement caused by dynamic behavior of penetrated pipe is directly dependent on ground condition beneath the track which has a significant effect on train operation speed and safety. Thus, it's necessary to analyze the cause of ground behavior in evaluating the effect of non-open cut method on trackbed as well as to identify the relationship between the top soil excavated and deformation distribution.

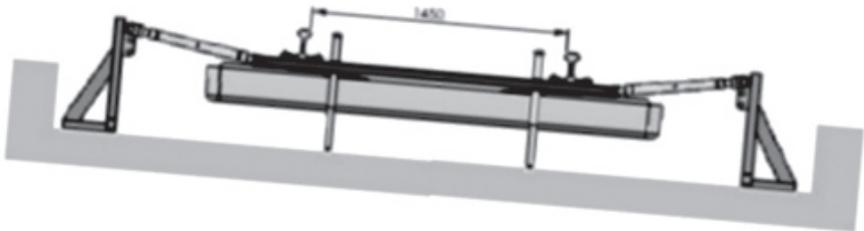
Hence, in this study, appropriate scale model was selected considering local geographical features and operation characteristics of high speed rail and traditional train and the ground settlement patterns were grouped by category and finally, displacement patterns were compared and evaluated using a certain criteria of ground loss based on excavation

progressed. To that end, a scale model was formed depending on compaction degree and the characteristics of the entire ground behavior by friction resistance around the pipe when pipes were penetrated into the ground were monitored.

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Balfour Beatty Rail Technologies specialises in decision support of railway maintenance and renewal operations, and in the creation of new technology to perform those operations in a cost-effective manner. Technologies, part of the worldwide Balfour Beatty Rail group, operates on the areas of track, structures and signalling where it not only develops new technology and software, but also provides consultancy services in support of these. The company is organised into three divisions, Signalling Systems, Laser Rail Technologies and Technical Services.

- **Signalling Systems** develop technology which enhances the performance of conventional railway signalling, through “intelligent infrastructure” – systems and software which monitor the performance of signalling, points and interlocking and advises of incipient problems.
- **Laser Rail Technologies** develops measuring systems and analytical software which can be used to monitor track geometry and infrastructure gauge – maximising capacity and durability.
- **Technical Services** provide a host of support consultancy covering use of its own systems and emerging new technology such as new track forms, track stabilisation, novel techniques and production methods.

Burdens Rail

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Delivering Sustainable Railways

Burdens Rail has been established to provide a sustainable supply chain to support the expanding rail network. It builds on over 80 years of Burdens' experience and its market-leading position in supporting the civil engineering and utility industries with the supply of materials and on the Group's already extensive rail experience and expertise.

The unique Burdens co-ownership business model ensures its own sustainability and offers a 'better way to do business' for the industry,

The Burdens Rail product range is uniquely tailored to rail industry requirements including:

- embankments and structures
- stations
- car parks
- permanent way.

Edilon)(sedra bv

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edilon)(sedra develops, designs, manufacturers and markets a wide range of products and systems for the attenuation of noise and vibration on ballasted and non-ballasted track for bridges, viaducts, tunnels and level crossings.

These systems have a long and ongoing history of R&D for tram, metro, rail, heavy haul, ports, depots and crane rail systems.

We are not just a supplier of railway products but can offer complete technical solutions, tested and approved in accordance with the latest European standards.

The edilon)(sedra expertise extends to:

- working in conjunction with operators/designers/consultants
- mathematical modelling
- technical support
- sample & system testing (in-house & external)
- on site supervision (edilon)(sedra contracting bv)
- edilon)(sedra actively markets products, systems and technical expertise worldwide.

ERPem – Edinburgh Research Partnership in Engineering & Mathematics

CEE JRI – Civil and Environmental Engineering (CEE)
Joint Research Institute (JRI)

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The aim of the CEE JRI is to generate new understanding in the interrelated fields of civil and environmental engineering, and apply the results to practical applications that address societal needs in the areas of adapting to climate change, sustainable development, infrastructure development, and personal and national security.

Civil and environmental engineering are the broadest of engineering disciplines making it difficult to define clear boundaries. This is in fact a strength, which makes them an exciting and dynamic discipline able to adapt with changing times to provide novel and innovative solutions to the myriad emerging challenges of the modern world.

These include the conventional areas of quality of life, public health and welfare as well as the emerging key goal of UK government policy: sustainable development. Sustainable development encompasses concerns on environment and climate change, resource depletion, dense and complex urban environments, changing demographics in industrialised countries, rapid development and industrialisation in Asia, poverty in Africa, pressures on water resources and public disorder and terrorism.

Clearly many other disciplines are involved in the study of these challenges, but it is always engineers - and often primarily civil engineers - who must find solutions to them under severe economic constraints.

The JRI will build on existing strengths in the areas of:

- High Speed Rail research
- intelligent infrastructure
- contaminant containment and subsoil environments
- transportation
- water management
- particulate and granular solids and soils
- structural engineering
- fire safety engineering
- innovative materials for the built environment.

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Contact: Sabrina Moore

UK manufacturer of geotextiles and geocomposites for permanent way.

Tracktex sand-blanket replacement: a micro-porous filter sandwiched between two thick protection textiles which acts to prevent the ingress of water through the ballast into the sub-ballast yet allows moisture, not fines, to pass upwards when dynamically loaded - Network Rail Certificate of Acceptance 0504238.

Protexia RK1 (also known as GHP3RT): a thick, robust geotextile that is deployed between ballast & subgrade as a filter/separator to extend the maintenance interval - Network Rail Certificate of Acceptance 00059

Protexia RK4: a laminate of RK1 & a geogrid which provides both separation & reinforcement for construction over weak, poorly-draining subgrades - Network Rail Acceptance Advice Note 02772.

A full-sized track rig is available for trialling products at the ballast:sub-grade interface.

GREX - Georgetown Rail Equipment Co

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Georgetown Rail Equipment Company is a United States based company, providing innovative tools and equipment, primarily to North American Class 1 Railroads, Transits and Regional Carriers. A privately held Texas corporation serving the Railroad Industry since 1992, GREX has grown from its original flagship products such as the Dump Train and Slot Machines into technology offerings including Aurora (Automated Track Inspection using Machine Vision) to Solaris (Automated Ballast Delivery) providing safer, more efficient and more productive methods to automate track maintenance tasks.

This summer, GREX will introduce Ballast Profiling technology as the next step in providing total ballast assessment, management and automated delivery. The system, an extension and improvement of the already successful GateSync product, is designed to measure the desired ballast profile against the existing ballast profile to provide an exact need assessment.

Accomplished in a 'pre dump' survey using a Hi-Rail vehicle, the information collected in advance of the survey is managed and streamed into the actual 'dump run' calculations for exact, human free delivery, precisely where needed at speeds up to 16 km per hour. Annual savings potential is estimated to reduce ballast requirements by at least 5% to 25% over past methods of relying on local experts to visually estimate the correct ballast requirement.

Innovative Support Systems Limited

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Contact: Phil Richardson

UK manufacturer of innovative support systems aimed specifically at railway construction and refurbishment where speed and simplicity of installation is required.

- **RAMWALL** – a rapid construction, free-standing or earth retaining wall system for temporary or permanent use, fabricated from standard steel reinforcement mesh and filled with new or recycled materials including track ballast to form a continuous, extremely robust structure. All steel components are easily manhandled and assembled in-situ and are delivered to site on pallets. Installation requires only minimal training and filling of the assembled structure can be undertaken mechanically using standard site plant. **RAMWALL** is approved by London Underground and Network Rail.
- **RAMARCH** – a rapid installation tunnel, shaft and viaduct arch support system for temporary or permanent use, fabricated from standard steel reinforcement mesh. The arch is assembled from easily manhandled panels using simple hand tools and can be installed mechanically to avoid the need for operators to enter potentially hazardous areas. The system, which is approved by Network Rail, provides temporary protection for refurbishment schemes and can be used in conjunction with sprayed or cast-in-situ concrete to produce a permanent support structure.

All steel components are manufactured to British Standards, CARES approved and can be galvanised or coated for corrosion protection.

Lusas

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LUSAS develops, markets and supports a range of finite element analysis software products for the engineering and construction industries. One product, LUSAS Bridge, provides a range of facilities and software options for the cost-effective design, analysis and load rating of all types of bridges.

With LUSAS Bridge, fundamental frequency, seismic, dynamic, nonlinear, buckling, fatigue, staged construction, modelling of concrete creep and shrinkage, heat of hydration, and prestress / post-tensioning can all be undertaken. Explosion, fire and damage assessments can also be made. Geotechnical facilities permit modelling of soil structure interaction, useful for integral bridge analysis, as well as for tunnelling, excavation and slope stability work. Extensive results processing facilities include Smart load combinations, mesh-independent slice sectioning, a user-defined results capability, a report wizard, and easy to use graphing, contouring and animation of results.

Of a number of software options that are available:

- A Traffic Load Optimisation software option provides worst-case vehicle and train loading patterns to a number of design codes including Eurocode and AASHTO.
- A Rail Track Analysis software option permits track/structure interaction analysis to be carried out to the International Union of Railways Code UIC 774-3 enables the interaction between the track and the bridge as a result of temperature and train loading to be investigated for high speed or light rail trainset loading.
- An Interactive Modal Dynamics option provides dynamic response results for a structure for a range of train speeds.

LUSAS software has been used by engineers worldwide for over 25 years.

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XiTRACK Limited is a joint venture company formed with partners 2Ei Ltd and Dow Hyperlast. This company operates in the rail industry providing computer aided designs for solutions to rectify many long standing engineering track problems. In the UK the application of the XiTRACK Process is carried out by the Project Partners Balfour Beatty Rail Technologies.

The XiTRACK™ Process uses state of the art computer software specifically devised and developed to simulate and predict railway track behaviour before and after polymer treatment. These programs are based on enhanced 3-Dimensional finite element techniques featuring advanced mathematical models of material behaviour.

XiTRACK Limited, as a Joint Venture partner with Dow Hyperlast, can benefit from the global reach, manufacturing capabilities and technical support of Dow Polyurethane (PU) Systems, a global leader in the development and formulation of fully formulated polyurethane systems for a broad range of applications with various facilities strategically located across Europe, Asia, Middle East, Africa, North and Latin America.

The Process has been successfully used on projects for over 11 years. Examples of these projects can be found on the website by visiting www.xitrack.com.

