Rail Research UK

The universities' centre for railway systems research

Appraisal of Track/Sub-base Performance Using Modern Instrumentation and Geotechnical Engineering Principles

Prepared for The Railway Safety and Standards Board

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Report on start-up funding for RRUK Project A1: Appraisal of track/sub-base performance using modern instrumentation and geotechnical engineering principles

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Summary of progress

The RSSB funding has allowed us to:

1. expand on the ideas originally proposed for project A1, so that the scope of the project could be defined in greater detail. This was achieved by conducting a study of relevant literature, further background reading and an investigation of suitable instrumentation. Also, we have been able to develop a greater understanding of the safety benefits of the research to be carried out in project A1. With regard to the instrumentation, it is hoped that this project will build upon the recent study in Sweden on high speed lines on soft ground [1]. To this end, the Swedish work has been examined in greater detail to identify the successes and failures of their instrumentation.
2. set up administrative support for RRUK Centre South at Southampton, by identifying and appointing an administrator (who is now in post).
3. set up the financial arrangements between Southampton, the EPSRC grant holder for RRUK, and the six other partner universities.
4. publicise the RRUK's Engineering Interfaces Theme (A), including project A1, by writing an article that will be published in the next edition of the quarterly European Railway Review. Also, we have established contact with the International Railway Journal who have requested that we write an article later this year to publicise RRUK as a whole.
5. begin work on setting up the Theme Network.

The remainder of this report focuses on project A1: a revised scope of study is presented and the safety benefits of the project are discussed.

Safety benefits of project A1

According to the 2002/2003 Railway Safety Research Programme [2]:

> Infrastructure integrity is fundamental to the safe operation of the railway. Infrastructure failures can act as precursors to catastrophic train accident hazards involving the derailment of trains and the collision of trains with other trains or structures. The principal groups at risk from such train accidents are train passengers and members of the train crew.
>
> Infrastructure includes track and earthworks.
>
> Hazards include rail buckles and breaks, faults in track geometry and structural failures.
>
> The underlying causes of such hazards arise from a number of factors including design deficiencies, increased rail traffic, faster line speeds and heavier axial loads.

In this context, the safety benefits of project A1 are clear: a more fundamental understanding of the response of the trackbed to train passages and a more robust approach to design should allow the long term behaviour of the trackbed to be anticipated. This is important because the properties and behaviour of the trackbed affect the degree to which the optimum track geometry is maintained. Also the safe capacity of a track, in terms of train frequency, speed and weight, is ultimately governed by trackbed performance.

As well as the primary effects of poor trackbed performance, it may be argued that an inadequate trackbed stiffness and poor track geometry will result in rail defects due to the more onerous rail stresses caused by increased dynamic loading effects. Such secondary effects are difficult to quantify but some RSSB research currently underway is trying to identify a link [2]:

> Influence of track bed stiffness on the incidence of rail defects. The project will investigate the possible role of track bed stiffness in determining the likelihood and nature of rail defects.

Hence, project A1 should also have the long term effect of reducing the incidence of rail defects.

So that the safety benefits of the research conducted in this project will be realised, the results will be disseminated widely as reports available through the RRUK website, through the theme networks (reports and presentations) and at international conferences.

Scope of project A1

Aims

- To assess the robustness of traditional track system/sub-base design methods, in comparison with a more fundamental, modern soil mechanics approach
- To explore the potential of a more fundamental approach to guide design decisions on the basis of optimised whole-life and whole-system costs
- To explore the potential of the application of a more fundamental understanding of track/sub-base system behaviour to performance assessment, maintenance planning and novel remediation techniques

Background

It is now recognised that financial investment in railways must be accompanied by advances in infrastructure technology if a successful, reliable and efficient rail service is to be delivered [3]. This is reinforced by the fact that during 2001/2002, 50% of all delays to passenger services were attributed to Railtrack (now Network Rail) [4]. Arguably, the key limitation to improving infrastructure is that our current understanding of trackbed and subsoil performance is poor, particularly in the context of a high speed and heavily trafficked railway [5,6]. Furthermore, following privatisation of the rail industry, there has been a change of emphasis from initial construction cost to Whole Life or Life Cycle Cost [5]. It is also now realised that increasing the number of trains will not reduce overcrowding because the physical capacity of the network has been reached in areas where extra capacity is most needed [3]. Thus, rail owners and operators are increasingly considering the construction of new track in response to the growing demand for rail traffic and freight movement in the UK and elsewhere.

In areas where the trackbed has significantly deformed or failed, ballast adjustment, which can be dealt with by repacking during short overnight track closures, usually only results in a temporary improvement to track geometry. Hence maintenance costs can escalate for a particular section of track, with little apparent reduction in the number of delays imposed on the train service [7]. Such sections of track ultimately require lengthy closures to allow complete excavation and replacement of the trackbed to take place if a long term solution to the problem is sought. This type of remedial work is expensive and disruptive, especially when compared with ballast adjustment, but the benefits may well include long term cost savings. However, our current state of knowledge does not allow reliable estimates of the life of the formation or of the benefits that would accrue, for example, from thicker track foundations. In particular, current design methods take no account of the effects of the cyclic principal stress rotations that occur as each bogie passes a particular point or the differences that result from trains of different speeds and axle loadings. Thus, the development of a proper scientific understanding of the dynamic load-deformation response and track/sub-base interactions would have enormous benefits in the design of new and replacement track systems, the development of remediation and maintenance strategies, the assessment of track system performance and the optimisation of whole life and whole system costs.

Work content

The main elements of the project are to:

- obtain high quality field measurements of the dynamic loads applied to the track system by trains (magnitude and frequency); of the sub-base, sub-soil and track system response using geophysical methods for dynamic movements and stiffness, chain deflectometers for permanent movements, load cells and pore pressure transducers as appropriate
- carry out advanced laboratory cyclic and dynamic tests (e.g. torsional hollow cylinder) to determine appropriate constitutive relations for typical sub-base materials in relevant stress paths, in particular taking into account the effects of principal stress rotation
- use the constitutive data in numerical analyses of track/sub-base systems, and compare the calculated responses with those measured
- assess the robustness and shortcomings of current track system and sub-base design methods with reference to the results of the numerical analyses and the field data
- investigate the potential of the more fundamental approach as a design support tool to assess whole life and whole system costs
- identify appropriate methods of performance assessment and parameter measurement for use in simple design methods, on the basis of the more fundamental understanding of track/sub-base system behaviour obtained

We will use sections of a new, high speed railway as the basis for the fieldwork component of the research. This is because

- a new railway will have good quality site investigation data for the characterisation of the sub-base materials and a fully documented basis of design
- the track system and sub-base will be subjected to relatively onerous loading by frequent, long, high-speed trains
- it offers the opportunity to monitor the response of sections of track that are likely to have different characteristics

In addition, The University of Birmingham will continue to monitor sections of track at Leominster, Herefordshire, to provide a comparator representative of many parts of the existing railway network.

Instrumentation

Aims of the instrumentation

1. to evaluate the loads/stresses experienced by the sub-base as a train passes over
2. to measure the transient and permanent deformations of the track, ballast and sub-base
3. to determine any long term changes in the stiffness of the sub-base
4. to provide suitable data for validating numerical models

Instrumentation overview

Provisional layouts for the instrumentation are given in Figures 1-3, which show the basic instrumentation layout, extended layout for embankments and a plan view, respectively. The basic instrumentation layout will have vertical boreholes either side of the track for geophysical tests; for an embankment the boreholes will be horizontal. To allow the stated aims to be met, the following instrumentation has been identified:

Falling Weight Deflectometer (drop weight tests) will be used to measure Rayleigh wave propagation velocities for comparison with results from other projects and numerical work. It will also allow evaluation of the critical velocity of the track/embankment system in a way increasing used by the railway industry [7] and would facilitate a direct comparison with the section of track monitored at Leominster by the University of Birmingham.

Geophysical Investigations will be carried out to calculate the horizontal stiffness of the sub-grade. The stress-strain behaviour of most soils is non-linear and so the calculated stiffness will only strictly be valid for the small strain levels induced by the seismic waves. However, the reduction in stiffness with increasing strain is small for the strain levels typically encountered around structures (0.01 to 0.1%). Also, stiffness measurements from geophysical techniques are thought to be more realistic than those derived from more traditional techniques, such as triaxial tests, which have been shown to underestimate stiffness by an order of magnitude [8]. The stiffnesses derived from geophysical measurements are therefore likely to be the most appropriate for numerical analyses of the sub-grade. In any case, if the working strain levels are estimated, it may be possible to use a reduction factor to define an operational stiffness to further refine the accuracy of numerical analyses. The particular geophysical technique employed will be the cross hole method where a source in one borehole is used to generate shear waves whilst geophones in other boreholes are used to calculate the wave travel time and hence speed (which is a function of stiffness).

Multi-depth Deflectometers will be included below the centre line of each track. The deflectometers will be of the type used extensively by Spoornet, comprising a vertical access tube grouted into the formation, within which an LVDT (Linear variable differential transformer) spindle and a number of sensor coils are contained. It is desirable that the measured displacements are absolute and so it is necessary for the base of the spindle to be anchored at a depth where the effects of the passage of a train are negligible. Monitoring at the Ledsgård site in Sweden measured displacements down to a depth of 8 to 10m for high speed trains (200km/h) [1]. Hence a depth of 12 to 15m will be used to anchor the LVDT spindle.

TDR Soil Moisture Probes will be included at various locations in the sub-grade below the tracks. TDR (Time Domain Reflectometry) is an accurate method of assessing the volumetric moisture content of a soil. It works by measuring the dielectric constant of the soil, a property which is a function of the soil moisture content. The presence of these probes will allow us to identify the location of, for example, any wet spots within the sub-grade.

Pressure Cells and Piezometers will be included at 5 different depths below the centre line of each track. It is not known whether the pressure cells will yield useful results within the soil, but their accuracy may be assessed by comparison with the loads deduced from the stiffnesses and displacements. The pressure cells will be of the total pressure type, i.e. they measure the combined pressure of effective stress and pore-water pressure, and be placed horizontally within the embankment. For automatic data logging, they will have to be of the vibrating wire type. The piezometers will measure the pore fluid pressure in the soil. For automatic data logging, vibrating wire or electrical piezometers must be used, although electrical piezometers are preferred because they are more suitable for measuring dynamic changes.

Accelerometers will be placed in horizontal tubes included in the embankment instrumentation (they will share tubes with the geophones used for the geophysical measurements). They will provide vertical particle accelerations during train passages and these results may be integrated and processed to yield dynamic displacements which will be used to cross-check those from the multi-depth deflectometers.

Rail instrumentation. Ideally, for accurate modelling of the stress/strain behaviour of the sub-grade, it is necessary to know the loadings transferred from the rails to the sleepers, and the sleepers to the ballast. Ways of measuring the loads transferred are still under investigation. It is also intended that strain gauges be used to quantify the deformations of the rails. These will have to be glued to the rails when they have been welded to their continuous state and tensioned.

A Weather Station will monitor rainfall, temperature, atmospheric pressure and solar radiation, so that instrumentation measurements may be correlated with environmental conditions.

Data Logging and instrumentation need to be switched on in advance of a trains arrival and a certain time after it has passed. At Ledsgård, displacements were measured at least 30m in advance of and 75m after the passage of a 110m long train [1]. Hence triggering the instrumentation a train length before the train reaches the instrumented section and turning it off after the train has passed the instrumentation by one train length would appear sufficient to capture the whole of the trackbed/track system response. It will also be necessary to log the number of train passages which may be done by simply counting the number of times that data logging has been turned on and off.

The Speed/Position of the Train. To be able to analyse the tail wave which follows a train and correlate the instrumentation measurements with load positions, including measuring any phase shift between axle loads and maximum displacements for high train speeds, it is necessary to know accurately the location and speed of the train while data are being logged otherwise measurements will be with respect to time only. One way of solving this problem would be to use a laser/light sensor system to sense the position of a part of the train. As trains may vary in length and composition (different sets), simply measuring the time of passing of the nose and tail of the train will not be of any use. Hence, if this method were to be employed, it would have to be set up such that it detected the position of individual wheels. As the distances between wheels are known, this will allow the speed of the train to be calculated. The problem with this approach, however, is the frequency at which data would have to be logged such that the position of an individual wheel may be determined. If, for example, a 25cm portion of the wheel cuts the beam and the train speed is 300km/h, this corresponds to a frequency of 333Hz. This aspect of the instrumentation is still under investigation.

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Figures

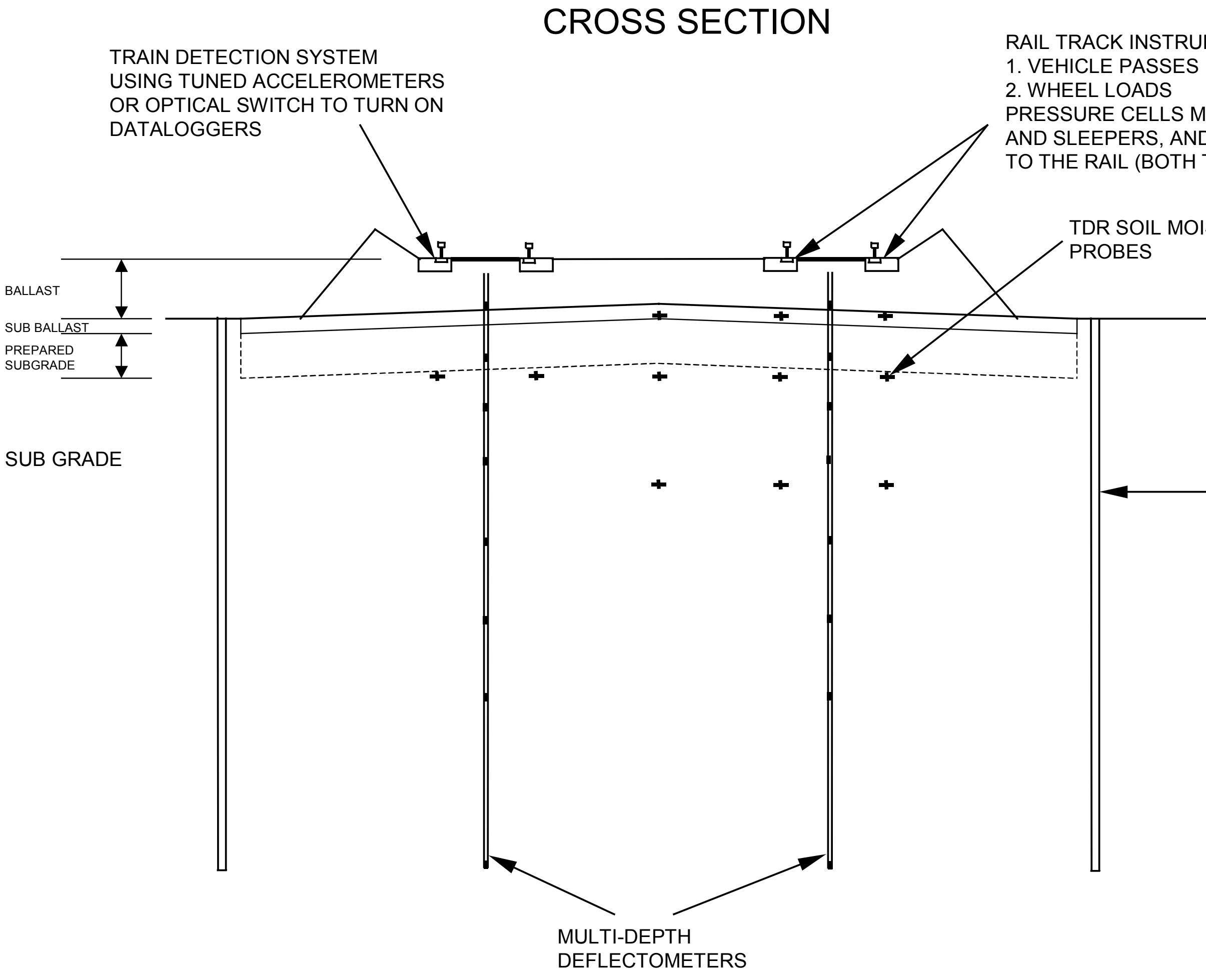

Figure 1 - Basic Instrumentation layout

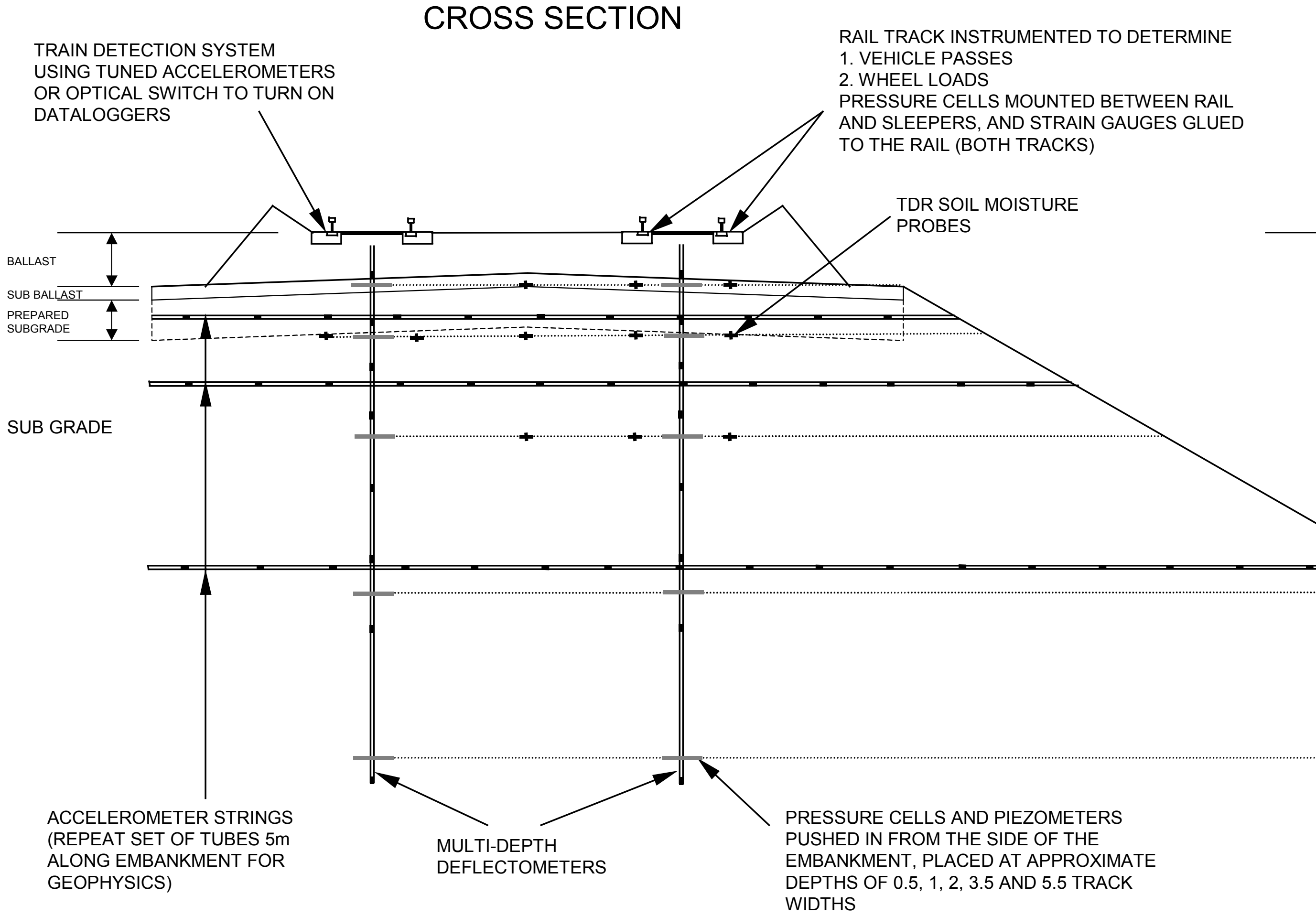

Figure 2 - Extended instrumentation layout for embankment site

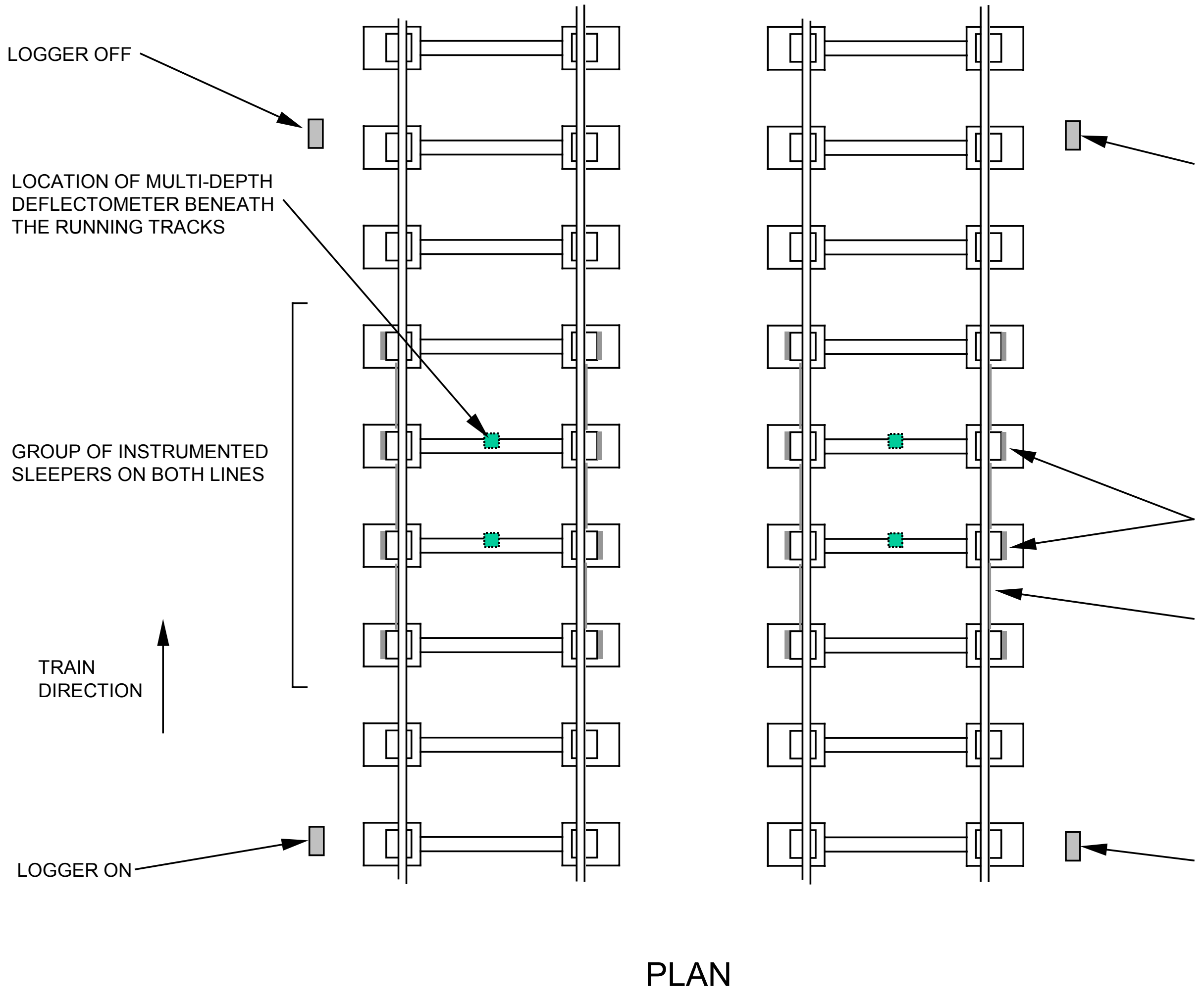

Figure 3 - Plan view of instrumentation

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