INTERACTIONS BETWEEN THE GROUND, TRACK SYSTEM AND TRAIN

RECENT YEARS HAVE SEEN SIGNIFICANT EXPANSION IN PASSENGER AND FREIGHT VOLUMES ON RAILWAYS ACROSS THE WORLD. IN ADDITION TO THIS INCREASE IN OVERALL TRAFFIC, THERE HAVE BEEN MOVES TOWARDS BOTH HIGHER LINE SPEEDS ON PASSENGER ROUTES AND HEAVIER AXLE LOADS FOR FREIGHT. THESE CHANGES PLACE INCREASING DEMANDS ON THE RAILWAY INFRASTRUCTURE GIVING RISE TO INCREASED OPERATING COSTS, ESPECIALLY WITH REGARD TO TRACK MAINTENANCE.

A better understanding of railway track performance could lead to significant reductions in cost though the development of more effective life cycle maintenance strategies, since maintenance accounts for a large proportion of the running costs of railways. To this end, Rail Research UK* (RRUK) – the Universities' Centre for Railway Systems Research established by the U.K.'s Engineering and Physical Sciences Research Council – has initiated a research project (designated Project A4), to study and improve the understanding of the interactions between the ground, the track system and train vehicle behaviour for ballasted railway track.

A consortium of 13 research groups in 8 universities within the U.K., RRUK has carried out a number of research projects since its inception in 2003. These are grouped under three broad themes titled Engineering Interfaces, Whole System Performance and Users, Communities and the Environment. *Project A4*, within the Engineering Interfaces theme, is a collaborative research project between the School of Civil Engineering and the Environment and the Institute of Sound and Vibration Research (both at the University of Southampton/UoS), and the Centre for Railway Research and Education (University of Birmingham/UoB), which started in September 2006.

This short article describes the current work on Project A4, which is directed at (a) *measuring and understanding the behaviour of railway track systems under different conditions of train loading*, and (b) *understanding interactions between the track system, trains and the underlying ground*, through the development and application of numerical models.

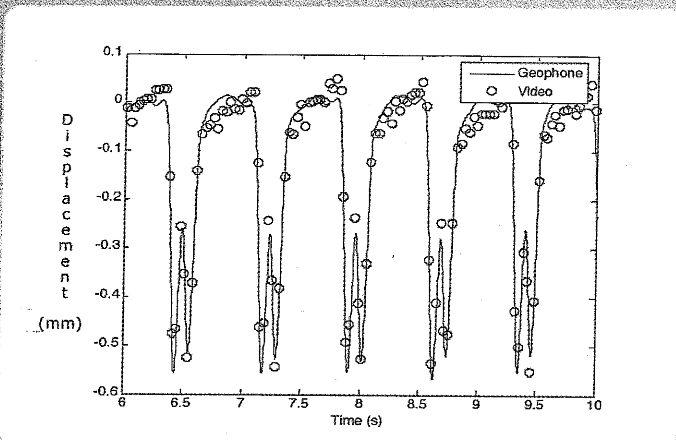


Fig. 1. Comparison of video and geophone data for a sleeper on a section of High Speed 1 line (formerly CTRL), U.K. (geophone data have been migrated to a zero datum[1])

Measurements of track system performance

Project A4 builds on earlier research conducted within RRUK (Project A1) that developed two novel, independent approaches to monitoring the dynamic response of the components of a track system (rail, sleeper or ground) during the passage of a train. One approach utilised high-speed digital photography with Particle Image Velocimetery (PIV) to measure displacements. The second approach used low frequency geophones (velocity sensors) to measure dynamic motion, from which displacements could be calculated by integration.

Figure 1 shows the response of a sleeper during the passage of a Class 373 Eurostar train over a section of monitored track: the passage of individual bogies and axles is clearly identifiable. These measurement techniques have enabled detailed information on track behaviour to be obtained for a range of different track conditions, which will facilitate investigation of the interactions between the components of the railway system.

Figure 2 shows the maximum displacement response of a sleeper during passage of a number of trains at different speeds on a section of the High Speed 1 line, near Ashford (Kent, U.K.). It displays the increase in track deflections with increasing train speed, suggesting an amplification of the train load with increased speed. Current UIC railway track design guidance has no amplification factor >> p.132

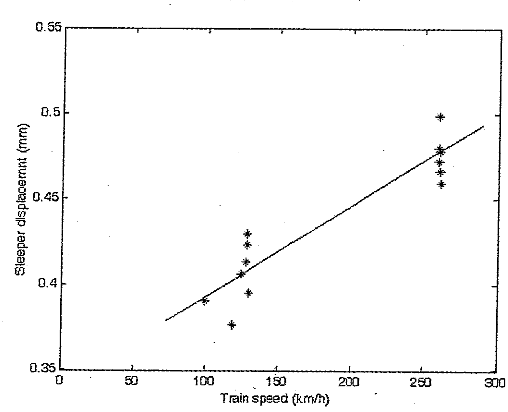


Fig. 2. Maximum sleeper displacement as a function of train speed

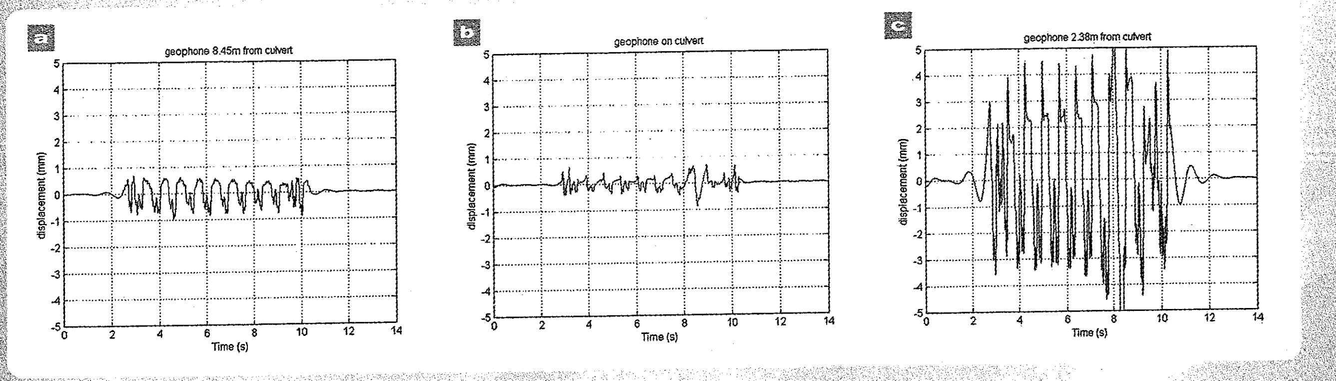
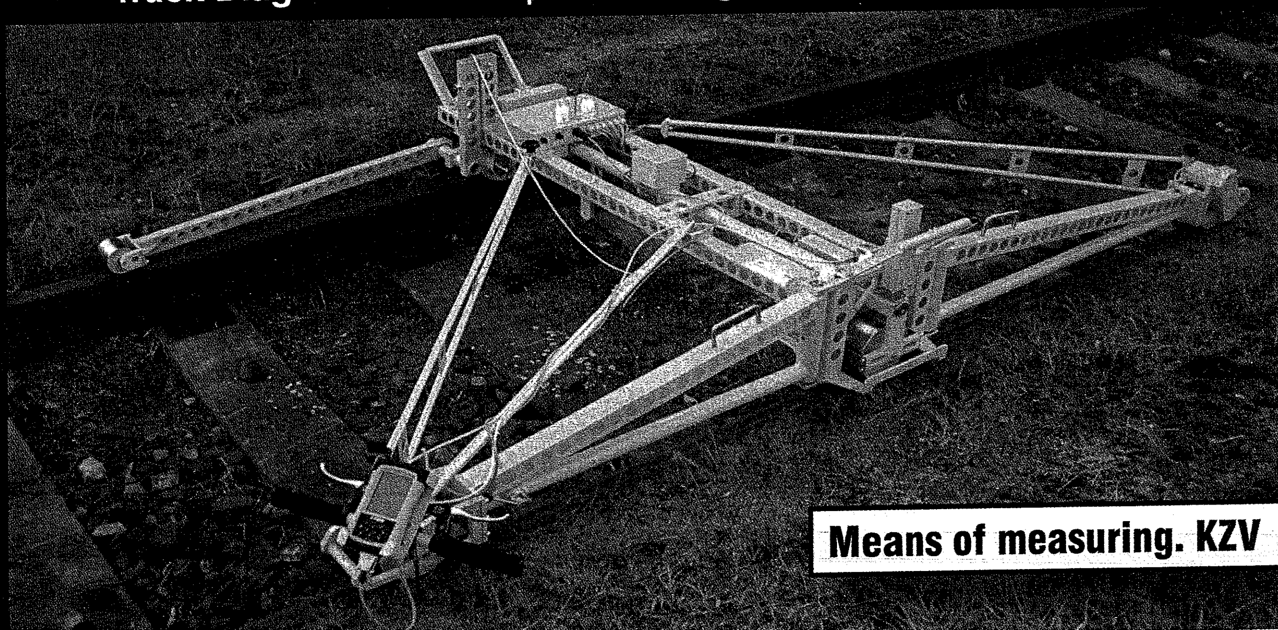


Fig. 4. Sleeper displacement for (a) standard track, (b) the transition zone and (c) over a culvert (concrete deck with 300mm ballast)

with partners in the Netherlands (Deltares and ProRail) to investigate the behaviour of track in transition zones: here the track substructure is designed to provide a gradual change in stiffness to or from an area of high stiffness such as an underbridge or a culvert. Transition zones have historically required more maintenance than standard railway track. Investigations were undertaken to measure the response of the track and ground within the transition zone and adjacent sections. Preliminary results (see Fig. 4) show that at the measurement location (section of track at Gouda Goverwelle, the Netherlands), the transition zone is of much lower stiffness than the adjacent track.

Work has also been undertaken to investigate the phenomenon of



<< p.130 for train loads. Given the ambition of railway companies to increase line speed beyond 30km/hr, the question is raised as to what effect this will have on track maintenance requirements.

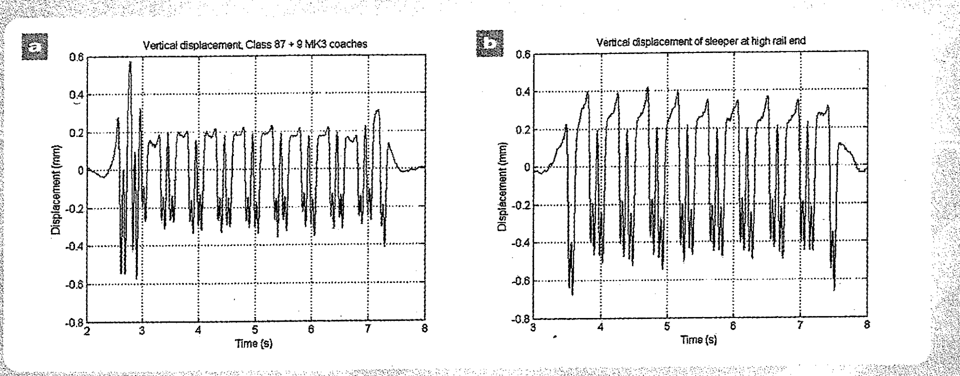


Fig. 3. Vertical displacement of a sleeper on the WCML during passage of (a) passage of Class 87 locomotive and nine Mk3 coaches, and (b) a nine-car Class 390 Pendolino train

The influence of changes in train loading on track behaviour is also being investigated[2]. The introduction of tilting Pendolino trains on the West Coast Main Line (WCML) has led to increases in both the line speed as well as the total axle load tonnage for this line. Figure 3 compares measured displacements of a canted track during the passage of a Class 87 locomotive pulling Mk 3 coaches with that from a Class 390 Pendolino. It can be seen that although the maximum axle load for the Class 87 locomotive is comparable to that of the Class 390, the number of maximum axle loads is greatly increased for the Class 390. As degradation of ballast and ground depends on both the magnitude and the number of applied load cycles, introducing Class 390 trains may increase track maintenance requirements. Localised events of ballast migration from the high to the low rail side of a canted track have been observed on sections of the WCML, raising questions over the cause of this phenomenon.

Field measurements have also been carried out in collaboration 'flying ballast' on high-speed railway lines, which can lead to damage to the underside of the train as well as to the rail head. Track velocity measurements using the geophones along with aerodynamic measurements (undertaken by the University of Birmingham) were made to allow quantification of the movements and forces generated at the ballast surface during a train passage. Early results suggest that neither aerodynamic forces nor induced ground vibration alone are sufficient to cause ballast uplift, indicating that the problem is likely to occur in specific circumstances when both factors interact.

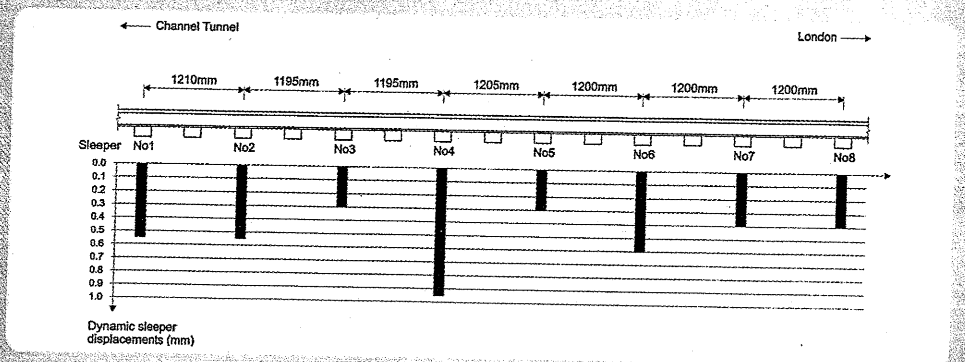


Fig. 5. Dynamic sleeper displacement for a section of track on HS1

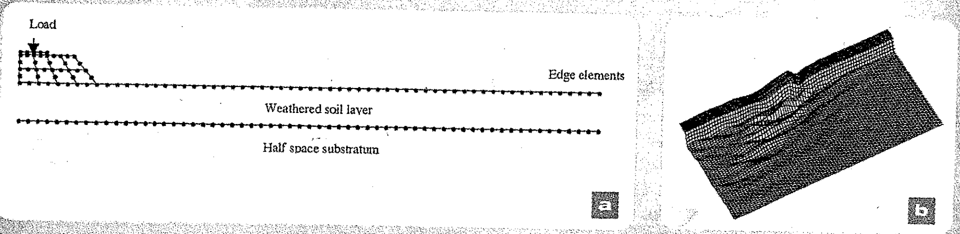


Fig. 6. (a) Model mesh and (b) example results from a '2.5 dimensional' model of track and ground vibration in response to moving dynamic loads[3]

Development of vehicle/track and track/ground interaction models

Figure 5 shows the measured displacements from a number of sleepers for a section of recently constructed track. This was built using the current UIC, railway track design guide and has a maximum line speed of 300km/hr. It can be seen that even over this short section, variations in the degree of track support are observed. Increased track deflections may lead to increased vehicle dynamic loads and long term damage. Vehicle dynamics studies are generally unable to include this information, as computer simulation packages use only very simple track dynamics models and hence do not allow the accurate representation of variations in track system support conditions. One aim of Project A4 is to build numerical models that can more accurately represent the true support response of the track, and its likely variation, for use in vehicle dynamics/track interaction models.

As high-speed mainline and metro rail networks extend into densely populated and vibration-sensitive urban areas, there is a need to understand the extent to which vibrations will propagate into the environment. Generally the moving displacements under the train loads cause the highest displacement at the track; however these are not the cause of propagating waves away from the track. The best understood propagation event is the dynamic loading due to track unevenness and wheel out-of-roundness. As the wheels roll they cause vibrations at the track, which then excite propagating waves in the ground. In Project A4, both this mechanism of vibration excitation and that due to the variation in track support stiffness will be studied by both modelling and analysis of field data. Figure 6 shows typical output from the model being developed.

Research into the future

Work within RRUK Project A4 is continuing and should be completed in early 2010. The combination of novel measurement instrumentation to provide high quality datasets of tack behaviour, coupled with advanced numerical models, will help us better understand the interactions between the ground, track system and vehicle behaviour. The hope is that this work will lead to improved maintenance strategies to help reduce life cycle costs, maximise capacity and minimise delays on railways ■

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[1]Bowness, D., A. C. Lock, W. Powrie, J. A. Priest and D. J. Richards (2007). Monitoring the dynamic displacements of railway track. Proc. IMechE Vol. 221, Part F: J. of Rail and Rapid Transport: 13-22.

[2]Priest, J. A., Le Pen, L., Powrie, W., Mak, P., and M. Burstow (accepted). Performance of canted ballasted track during curving of high speed trains. 1st International conference on Transportation Geotechnics, Aug 2008, Nottingham, U.K.

[3]Sheng, X. Jones C. J. C. and D. J. Thompson (2007). Modelling ground vibration from tunnels using wavenumber finite and boundary element methods. Proc. R Soc A 461: 2043-2070.