TRACK21:

Railway track for the 21st century

*WILLIAM POWRIE presents an update on progress on the **TRACK21** research programme*

In November 2010, Railway Strategies reported on the award of a collaborative research Programme Grant, *TRACK21.* Funded by EPSRC and led by Principal Investigator Professor William Powrie of the University of Southampton, the grant brings together researchers from the Universities of Southampton, Birmingham and Nottingham and a range of industry partners including Network Rail, HS2, LUL, RSSB, Balfour Beatty, Tata and Pandrol with the aim of bringing about step-change improvements in the ways existing railway track are maintained and new lines are designed and built.

The key research challenge addressed by *TRACK21* is to develop improved understandings of the complex mechanisms of railway track behaviour governing stiffness, robustness, longevity, noise and vibration. The research adopts a systems approach in which the track is considered holistically in terms of its interactions within itself, with trains and the environment. The ultimate goal is to reduce deterioration rates and maintenance requirements substantially, while at the same time mitigating the environmental impacts of noise, vibration and materials use. These are perhaps the most significant challenges facing railway systems today; if successful, the research will lead to reduced whole-life costs and improved timetable reliability, together with the accompanying financial, environmental and customer service benefits.

Two years in, considerable progress has been made in the following broad topic areas.

Field investigations of real track behaviour

Ballast migration

Figure 1 (from Priest *et al*, 2012) shows the phenomenon of ballast migration. This may occur on canted curved track traversed by high speed (~200km/h) trains, and involves the gradual migration of the ballast down the cant so that the high end of the sleeper is exposed and the ballast gathers in a heap against the low rail. A mechanism has been proposed to explain this behaviour, and is described in full in a paper soon to be published in the *Journal of Rail and Rapid Transit* (Priest *et al*, 2012).

Figure 1: Ballast migration (from Priest et al,2012)

Ballast flight

At high train speeds, turbulence induced by train passage – perhaps in conjunction with train-induced vibration of the ballast and ground – can result in small particles of ballast becoming airborne. This can damage the underside of the train, and the crushing of a particle left on the rail head can cause a form of damage known as 'ballast pitting' (Figure 2, from Quinn et al, 2010). The paper by Quinn et al (2010), describes field investigations which shed some light on the topic, although further work remains to be done.

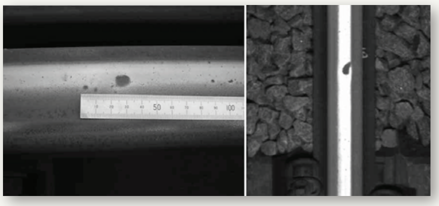

Figure 2: Ballast pitting (from Quinn et al, 2010)

Transition zones

Transition zones, where the track passes from ordinary ground onto a rigid substructure such as a bridge or a culvert, are potentially problematic in terms of ongoing differential displacement and increased maintenance requirements. The strategies adopted to try and mitigate these effects are sometimes spectacularly unsuccessful (e.g. Coelho *et al*, 2011) and further research into more effective designs is required. Within *TRACK21*, critical zones (including switches, transitions and underbridges) have been identified at various locations mainly on the southern region of the UK network, and their performance is being monitored both from the track and using on-train instrumentation developed at the University of Birmingham.

Deformations of earthworks subjected to cyclic seasonal changes in pore pressure due to vegetation and enhanced traffic loading

Cyclic shrink/swell deformations of earthworks embankments can cause major problems for rail infrastructure owners in terms of maintaining the required track levels. Fatigue effects might also lead to the gradual failure of such embankments over several decades.

These issues are being investigated in cyclic triaxial tests in which 70mm diameter specimens of Lias Clay embankment fill from a site near Bristol are being subjected to cyclic variations in pore water pressure of 100kPa, while maintained in a total stress state representative of a depth of 1.5m below the surface of an embankment. Further tests are being carried out in which the total stresses are being cycled at a much higher frequency, mimicking train passage. In both cases, the laboratory tests are complemented by field and full-scale studies: additional collaborators include Mott MacDonald, GeoObservations and Arup.

Effects of principal stress rotation on different types of track subgrade

A torsional hollow cylinder apparatus has been set up and a testing procedure developed, following Powrie *et al* (2007), to investigate the effect of the principal stress rotation associated with train passage on a variety of railway foundation soil types. Particular emphasis is being placed on the effect of clay content and the time interval between loading events. Current data suggest a reduction in the susceptibility of a sub-base material with increasing clay content, at least up to a clay content of about 16 per cent; although at some stage the reduced permeability will have a more significant adverse effect. Work on this aspect is continuing.

Investigating the effectiveness of ballast and sleeper modifications

The replacement of traditional timber sleepers by reinforced concrete has resulted in a much harder interface, with smaller and possibly fewer sleeper to ballast contacts and the increased likelihood of ballast particle breakage rather than embedment into the softer sleeper material. The University of Southampton sleeper testing rig (Figure 3; Le Pen and Powrie, 2011) has been upgraded to enable the long-term performance of different combinations of sleeper material (timber, plastic, steel) and shape (traditional, duo-bloc, inverted U); and also the effectiveness of under-sleeper pads in reducing sleeper/ballast contact forces.

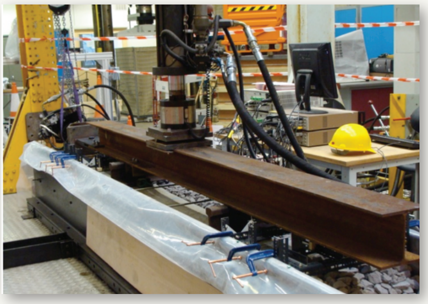

***Figure 3:* University of Southampton ballast and sleeper testing rig**

Rig tests typically involve up to three million load cycles, representing a cumulative load of 60 megatonnes and perhaps between a year and a decade's real use with no maintenance interventions. Lateral as well as vertical loads can be applied, simulating the effects of curving at a cant deficiency and/or sidewind loading. Handling the intensity of data produced is a significant challenge.

Settlement data from a typical test running to three million loading cycles are shown in Figure 4.

The introduction of a pressure-sensitive paper between the underside of a standard reinforced concrete sleeper and the underlying ballast has given an interesting demonstration that the sleeper is in fact supported on a relatively small number of particle contacts, which move around considerably during the course of many loading cycles (Figure 5).

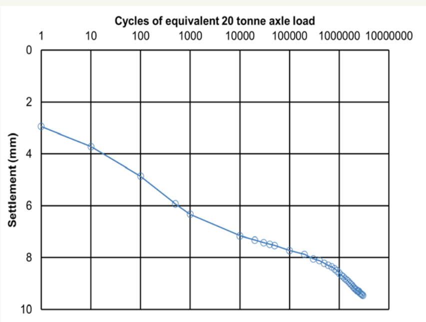

***Figure 4:* Settlement vs. number of loading cycles (log scale) for a G44 reinforced concrete sleeper on a 300mm ballast bed subject to an equivalent axle load on 20 tonnes**

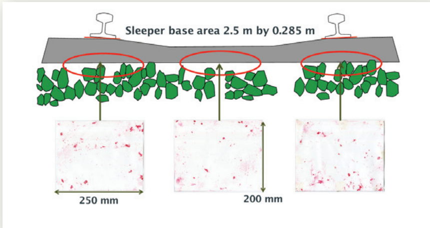

***Figure 5:* Sleeper-ballast contact point history over 2.5 million, 20 tonne equivalent loading cycles**

The influence of contamination with finer particles such as coal and sand is also being investigated. Complementary tests are in progress in the Nottingham sleeper testing rig (Brown *et al*, 2007), which simulates the effect of vertical loading under a moving train over a group of three sleepers.

In addition to the load-deformation response, the effect of any track system modifications on noise and vibration must also be considered. The dynamic stiffness of the ballast bed at higher frequencies is important in this respect, as it influences the transmission of vibration into the ground or supporting structure as well as acoustic radiation from the track. A new test rig to investigate high frequency ballast stiffness and noise mitigation effects is nearing completion. This will allow dynamic stiffness measurements to be made, both directly and indirectly, at frequencies between 50Hz and 1000Hz under a range of preloads.

Development of structure in railway ballast

It is well-known that ballasted track gradually settles as a result of trafficking, owing to deformation of the sub-base and/or of the ballast itself (Figure 4). Traditionally, the track is returned to the required level by lifting and tamping; unfortunately, this process destroys the structure that has been developed by trafficking resulting in a relatively much softer response during the initial reloading. This is illustrated by the results of triaxial tests on a scaled ballast simulating the effects of cyclic loading, tamping and reloading (Figure 6).

To complement the laboratory simulations using scaled ballast, methods have been developed to recover samples of trafficked ballast from below sleepers during track renewal operations, and to assess the arrangement and orientation of particles using computed tomography (CT scanning). Figure 7 shows sampling in progress, and Figure 8 a typical CT scan. Initial analysis suggests that the development of structure in ballast is associated primarily with densification and an increase in the number of particle to particle contacts, rather than gross particle reorientations.

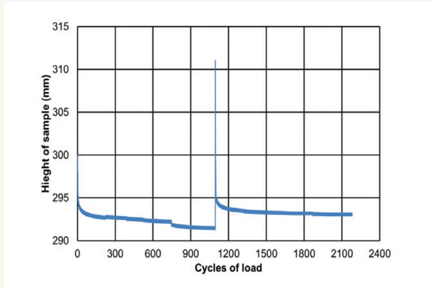

***Figure 6:* Results of triaxial tests simulating cyclic loading (cell pressure 50kPa, q varying from 5 to 150kPa), tamping (principal stresses reversed) and reloading showing the relatively soft response on re-loading after tamping**

***Figure 7:* Ballast sampling in progress**

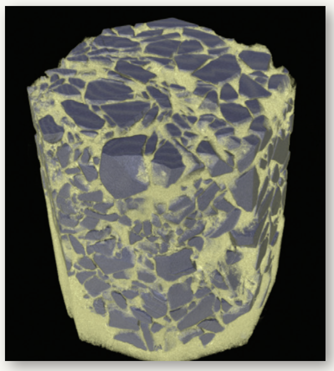

***Figure 8:* Typical CT scan of a ballast sample**

Further insights are being gained through numerical distinct element analyses at the particle scale, using particles representative of real ballast generated by means of the Potential Particle approach (Harkness, 2009). A typical numerical model of a triaxial test specimen made up of ballast particles is shown in Figure 9.

***Figure 9:* Typical distinct element numerical model of a triaxial test specimen made up of particles representative of real ballast, formed using the Potential Particle method (Harkness, 2009)**

Tampless Track

Causes of the progressive deterioration in track top geometry include settlement of the subgrade, ballast breakage and ballast fouling (e.g. Indraratna *et al*, 2011). In addition to the destructurization effects apparent in Figure 6, tamping causes particle breakage (Selig & Waters, 1994; McDowell *et al*, 2005) thereby further contributing to ballast degradation.

It follows that the maintenance requirement of ballasted track could be substantially reduced, and its whole life economic and environmental performance dramatically improved, by measures that include:

- Providing a firm sub-base
- Preventing fouling by fines from above and by soil from beneath
- Altering the ballast specification to enhance its mechanical stability
- Removing the need for tamping.

This is encapsulated in the *Tampless Track* concept (Figure 10), which has been developed as part of *TRACK21* as a way of drawing the work together into a form that will fulfil the aims of the project and facilitate their implementation in practice.

Further work is proposed on the suitability and development of ballasted track for very high speed trains (300-400km/h), which will include consideration of track geometry, ballast flight and mitigation of critical velocity effects.

Environmental and whole-life cost modelling

In addition to the continuation of the technical work outlined above, the second stage of *TRACK21* will see the development of environmental and whole-life cost models for different trackforms, based on robust data and analysis generated during the project. This will provide railway design and maintenance engineers with reliable tools to make decisions relating to initial construction and maintenance strategies for railway track systems in the future.

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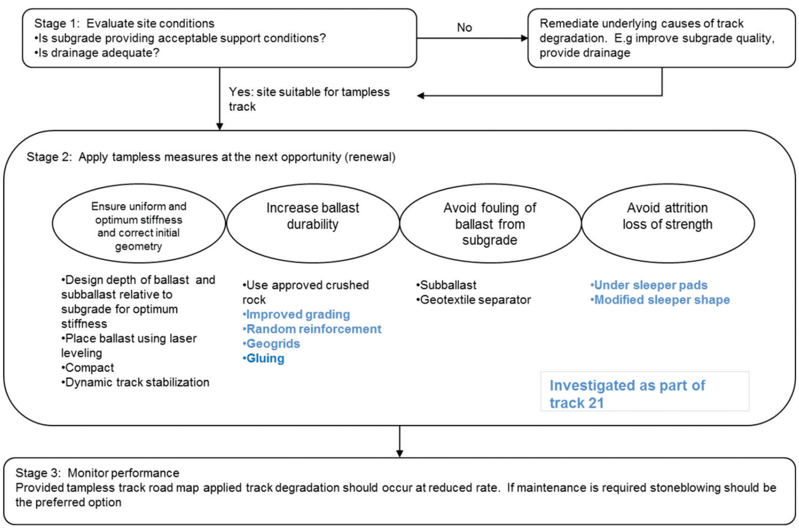

***Figure 10:* Tampless Track Routemap**

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