Institution: Edinburgh Research Partnership in Engineering – ERPE (Heriot-Watt/Edinburgh)

Unit of Assessment: B15 General Engineering

Title of case study: Increasing the efficiency of Railway Track Maintenance through Ballast Reinforcement and Numerical Geomechanics.

1. Summary of the impact (indicative maximum 100 words)

ERPE, through the application of XiTRACK technology (using advanced polyurethane polymers to reinforce the ballast matrix, enhancing strength, stiffness and resilience) - has reduced track maintenance by a factor of up to 40, increased maintenance intervals from 3-monthly to 10 years with track speeds increased up to 125 mph in critical sections of the UK, Italy and Hong Kong rail networks. Developments in Finite Element (FE) geomechanics related to Rayleigh waves are used by HS2; and FE backed artificial neural networks are informing US High Speed operators on ground borne vibrations. The financial impact of XiTrack is estimated at least £50M; and avoidance of Rayleigh wave problems and ground borne vibration mitigation, in the region of £10M; plus benefits to millions of passengers.

2. Underpinning research (indicative maximum 500 words)

The key researchers were: Prof Woodward, Prof Forde, Prof Laghrouche, Drs Connolly (L/ECR/formerly PGR), Giannopoulos (SL) and Medero (L). All researchers were active throughout the underpinning research period.

Overall, the three most important research activities from the ERPE research which enabled the impacts in XiTRACK and Railway Engineering geomechanics were:

- ERPE's (Woodward, Laghrouche and Medero) work in the numerical modelling of granular soils, in particular large diameter aggregates and their behaviour under cyclic loading (1993-2000) led to an examination of techniques that could reinforce geo-materials to improve performance. Woodward, aware of the use of polymer reinforced mortars for road cobbles, made the connection through to railways; he then developed and patented [P1] the XiTRACK technique using advanced polyurethane polymers. The rigour of the research behind XiTrack is underlined by Woodward's progression from a concept to authorship of a bespoke 3-D track focused FE software, DART3-D, verified by large scale laboratory experiments in GRAFT Rigs 1 and 2, and field proven on Network Rail track in the UK and latterly with field trials in Italy and Hong Kong in conjunction with Balfour Beatty Rail [S1]. This research to practice to industry take-up has provided new understanding of the year round, seasonal variations performance of polymer/XiTRACK stabilised ballast on actual site operational live track. [1-4].

- Work on numerical analysis methods by ERPE (Woodward, Laghrouche, Forde and Connolly) using DART3-D to examine the geodynamic behaviour of high-speed trains developed the concept of the ground Mach Cone as the train velocity approaches the Rayleigh wave velocity – thus generating large vertical track displacements which disturb the train's ride quality and stability. Further analysis shows the significance of the rolling stock and power unit suspensions longitudinal location layouts on the development of the mach cone as the train approaches the Rayleigh wave velocity. It shows that there is not a unique soil-structure "critical velocity", but rather a soil-structure-rolling stock configuration interaction. This reinforces the need for a non-linear 3-D FE analysis rather than a more simplistic 2-D analysis taking limited account of suspension geometry. This work led to EPSRC funding [G1] on high-speed track design and in turn led to consultancy for HS2 by Woodward. Two TSB grants on Rail Innovation ([G2] and [G3]) have also been funded. [3-4]

- ERPE research [G1] into high-speed rail has been used to reduce ground vibrations. Forde, Giannopoulos and Connolly have focused on ground borne vibrations emanating from high-speed trains and involved extensive field monitoring trials in the UK (HS1) and Belgium funded by NERC [G4]. This work strengthened the international database and enabled Abaqus 3-D FE models (run on a supercomputer) to be accurately calibrated. The work demonstrated that

the widely used (US) Federal Railroad Administration (2005) software to predict ground borne vibrations is simplistic and inaccurate. A more accurate, simple ground borne vibration demonstration model using neural networks based on the Abaqus models and verified by the UK/HS1 and Belgian data collection is now freely available (http://www.see.ed.ac.uk/drupal/IIE/infrastructure/railway-engineering/ground-vibration-software). This work has been extended to provide design guidelines for vibration mitigation using trenches backfilled with a low acoustic impedance medium. [5-6]

3. References to the research (indicative maximum of six references)
References identified with * are those which best indicate the quality of the underpinning research

[1]*Woodward, P.K., Thompson, D. and Banimahd, M. "GeoComposite Technology: Reducing The Railway Maintenance." Proceedings of the Institution of Civil Engineers, Transport Journal, Vol. 122, Part 3, pp. 135-139 (2007). DOI: 10.1680/tran.2007.160.3.109
Won 2008 Institution of Civil Engineers Best Paper Award, Webb Prize, Transport Journal. The paper describes application of the technology to reducing ground vibration.

[2]*Woodward, P.K., Kennedy, J., Medero, G. and Banimahd, M. "Application Of In-Situ Polyurethane GeoComposite Beams To Improve The Passive Shoulder Resistance Of Railway Track." Proceedings of the Institution of Mechanical Engineers, Part F, Journal of Rail and Rapid Transit, Vol. 226, Issue 3, pp. 294-304 (2011). DOI: 10.1177/0954409711420521
The paper discusses application of the technology to reducing track misalignments at switch and crossings.

[3] Woodward, P.K. El-Kacimi, A., Laghrouche, O., Medero. G. and Banimahd, M." Application Of Polyurethane GeoComposites To Help Maintain Track Geometry For Ballasted High-Speed Railway Tracks" Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering), Vol. 226, Issue 3, pp. 257-271 (2012). DOI: 10.1631/jzus.A12ISGT3
Discusses application of the technology to high-speed issues, in particular to bridge transitions.

[4] Kennedy, J., Woodward, P.K. and Medero, G." Reducing Railway Track Settlement Using Polyurethane Polymer Reinforcement of the Ballast." International Journal for Construction and Building Materials, Vol. 44,, pp. 615–625 (2013). DOI: 10.1016/j.conbuildmat.2013.03.002
The paper presents experimental data using GRAFT I to prove that the technology reduces track settlement over soft soils.

[5] Connolly, D., Giannopoulos, A. and Forde, M.C. ".Numerical modelling of ground borne vibrations from high speed rail lines on embankments", Soil Dynamics and Earthquake Engineering, Vol. 48, pp. 13-19 (2013). DOI: 10.1016/j.soildyn.2012.12.003
3-D finite element analysis of high speed trains (HST) running on an embankment, using Abaqus. was correlated with published data from HST in Belgium.

[6]*Connolly, D., Giannopoulos, A., Fan, W., Woodward, P.K. and Forde, M.C, "Optimising low acoustic impedance back-fill material wave barrier dimensions to shield structures from ground borne high speed rail vibrations", Construction and Building Materials, Vol. 44, pp. 557 – 564, DOI: 10.1016/j.conbuildmat.2013.03.034
First paper to consider the acoustic impedance of back-filled wave barriers to interrupt ground borne vibrations from High Speed Trains (HST) – it would enable the UK project HS2 to reduce vibrations in sensitive areas.

Grants

[G1] EPSRC, EP/H027262/1 & EP/H029397/1, £479k, Woodward, Forde, Lagrouche, Medero, Giannopoulos, "Development of Design Guidelines for High-speed Railway Track Including Critical Track Velocities and Track Mitigation Strategies", 2010-2013.

[G2] TSB, #101204, £230k, ERPE, University of Sheffield, Balfour Beatty Rail Technologies Ltd., "XiSPAN Bridge Strengthening and Life Extension", 2012-2014.

[G3] TSB, #101199, £297k, ERPE, Balfour Beatty Rail Technologies Ltd., "Formation Stiffness Measurement", 2012-2013.

[G4] NERC, Geophysical Equipment Facility Loan, 971, Forde, "Seismic Vibration Measurements near High Speed Railway lines, to validate University of Edinburgh developed software", 2012.

Patents

[P1] PCT/GB01/03679 Woodward, P.K. and Moss, R.M. 'Method of Stabilising Particulates' International Patent Number WO 02/16695 Al PCT, 2001.

4. Details of the impact (indicative maximum 750 words)

The invention and patenting of the XiTRACK technique led to the development of new innovative technologies to solve long-standing railway track problems, such as transitions, switch & crossing faults, track tolerance issues etc. In 2001, 2Ei Ltd, which is a spin out company from ERPE, formed a joint venture company (XiTRACK Ltd) with Hyperlast Ltd. In 2003, XiTRACK appointed Balfour Beatty Rail Ltd as the preferred installation contractor.

Implementation of XiTRACK across the UK railway network (and now overseas) demonstrates the application of new technology in engineering practice, from theory through to actual site application. It led to patent [P1] being filed in 2001 which resulted in the technology being adopted into the Network Rail (UK) procedures for the solution of ballasted track problems (Network Rail Approval Certificate No. PA05/01995) [S2]. XiTRACK allows accurate control of track forces, settlements and transient deflections. What this means is that the track is enhanced in terms of engineering performance and designability. XiTRACK is not applied across long stretches of track, as it resolves site specific problems, where stability and issues of track downtime are critical.

The Technique has been applied at many strategically important sites across the UK including tunnels, switch and crossings. Some examples of application are listed below:-

- Newham Bog: XiTRACK was used to stabilise the trackbed at Newham Bog on the East Coast Main Line in 2008 to prevent excessive track maintenance and hence improve track usage. The cost of installation of the XiTRACK element of the track work was £250,000 and to date performance has been very good [S1].
- Manningtree North Junction: XiTRACK was used to stabilise the track over an embankment containing switch and crossings situated on the Colchester to Ipswich line in 2008. The solution has significantly reduced track maintenance at the site [S1].
- XiTRACK was used to stabilise two adjacent high-speed switch and crossings (2000 and 2008) at Bletchley South on the West Coast Main Line. At the first site 10 years of maintenance free operation (normal maintenance period was every 3 months [6]) was observed and at the second site the system was installed to prevent the repeated failure of the switch and crossing, i.e. to stop the formation of rail cracking. The West Coast Mainline carries 75 million passengers per annum and 48% of all UK freight traffic (trains) [S1].
- The technology was used to stabilise the track bed at Clapham Junction in December 2008. It is one of the most important and highly used railway junctions in Europe with over 2,500 trains passing through Clapham Junction every day [6] [S1].
- In 2009, it was applied at Hoxton Station on the East London Line to provide a high fixity solution (within 0.06in [1.5mm] movement) to ensure that gauge clearances are maintained and hence track safety assured. This track forms part of the line that was used to support the 2012 London Olympics [3] [S1].

The sites listed above are critical sites to the operation of the UK rail network and the final site was critical to the transport of passengers for the London 2012 Olympics.

The technology is being developed by one of the world's largest chemical companies, The Dow Chemical Company, and by one of Europe's largest railway (and construction) companies Balfour Beatty. It has led to new staff appointments at these companies: in Dow Chemicals, polymer chemists and marketing; in Balfour Beatty Rail sales, technical and track installation teams [S1]. The technique has therefore gone full course, i.e. it was developed at ERPE as a new technology,

patented by ERPE, spun-out of ERPE into industry, trialled for a period of 6 years through a licensing agreement, obtained approval certificate by Network Rail and is now used to solve real track problems, including critical sites to the operation of the UK's rail and transportation infrastructure. Since 2011 the design process has been formally adopted by Balfour Beatty Rail Ltd to design XiTRACK track treatments for polyurethane treated sites both in the UK and overseas, specifically in Italy (Milan Metro slab-track to ballast transitions 2011) and Hong Kong MTR Station for lateral clearance issues (University Station May 2012)[S1]. The Hong Kong MTR operates over 1.5 billion passenger journeys per year.

This research has significant impact in the development of ballasted high-speed networks. This pioneering work is of particular interest to the development of the UK High Speed 2 line and hence Woodward has been appointed as a high-speed track consultant to HS2. Strong industry interest is demonstrated by ERPE consultancy from HS2 [S5] and the Transport Select Committee discussing ERPE research [S6].

The advanced geomechanics numerical modelling work demonstrated that the widely used (US) Federal Railroad Administration (2005) software to predict ground borne vibrations is simplistic and inaccurate. The key output creating international impact was a more accurate, simple ground borne vibration demonstration model using neural networks based on the Abaqus models and verified by the UK/HS1 and Belgian data collection which is now freely available (http://www.see.ed.ac.uk/drupal/IIE/infrastructure/railway-engineering/ground-vibration-software).
"The numerical analyses and ground borne vibration predictions from High Speed Trains (HST) are particularly important to geotechnical engineers involved in HST track design in the USA. The creation of the freely available through a weblink to predict these vibrations has had a substantial impact." [S7].

ERPE has established a Centre of Excellence in High Speed Railways in partnership with Atkins Global Plc. (one of the world's largest engineering consultancies) [S4]. Atkins Global is working closely with ERPE and Woodward has been appointed to the Atkins Chair of High Speed Railways and has built the UK's largest laboratory railway test track [S3], which complements the largest full scale outdoor railway test track at a UK university at the Kings Buildings campus.

5. Sources to corroborate the impact (indicative maximum of 10 references)

XiTRACK:

[S1] Head of Systems and Technology, Balfour Beatty Rail will confirm that Balfour Beatty Rail works with ERPE in the field of railway infrastructure innovation.

[S2] http://www.bbrail.co.uk/Products-and-Services/Track/Xitrack, which outlines how Balfour Beatty Rail apply XiTRACK technology and confirms full Network Rail Product Acceptance.

High-speed Railways:

[S3] Business Development Manager, Atkins Global who will outline how Atkins Global view the research and its application in a High Speed rail environment

[S4] http://www.atkinsglobal.co.uk/media-centre/press-releases/2013/2013-07-19 which confirms Atkins Global Plc.'s establishment of a Centre for Excellence with ERPE.

[S5] http://www.hs2.org.uk/press/rayleigh-waves-statement confirms Woodward's HS2 consultancy

[S6] http://www.publications.parliament.uk/pa/cm201012/cmselect/cmtran/writev/rail/m53.htm confirms discussion of ERPE research relating to HS2 at the Transport Parliamentary Select Committee, item 26.

Numerical Geomechanics – Ground Borne Vibrations:

[S7] Senior Consultant, GEI Consultants, Inc –. See comments in section 4