Project A	**Fibre Reinforced Ballast (FRB)**
Part of	**Research Challenge 1, TRACK4LIFE**
Project timing	Started June 2015
More information from	Dr Louis Le Pen
Project partners	Network Rail (NR) London Underground Ltd (LUL)
Associated projects	EU project In2Rail, H2020-MG-2014: Grant agreement 635900. WP3, Deliverable 3.3: T2F researchers wrote section 4.4.4 on FRB

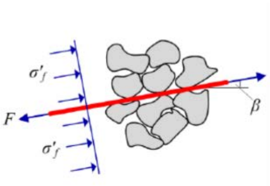
Project aims

Previous work had identified the potential benefits of adding randomly-placed fibre reinforcements to ballast-like materials, in terms of improving their strength and ductility, at least in monotonic loading. This project aims to develop further the science behind the approach, from concept to field trials, by:

1. establishing a conceptual framework to explain the observed benefits
2. cyclic triaxial tests on specimens of scaled reinforced ballast
3. extending the conceptual framework to encompass cyclic loading
4. exploration of the benefits of differently shaped reinforcing fibres through laboratory rig tests
5. a field trial to investigate the benefits on a live railway line.

Progress to date

Project aim 1. A conceptual framework that explains the benefits of random fibre reinforcement in monotonic loading has been developed [A1], and rules for reduced-scale tests established [A2]. The key conceptual and theoretical advance is that the tension developed in the fibres as the material strains increases the effective stress on the granular skeleton (Fig. A1). Thus behavioural differences between reinforced and unreinforced ballast are explained by differences in material state (stress and density), rather than changes in fundamental material properties as in most previous work on reinforced sands.



$$\frac{F}{A} = \sigma'_f = \frac{\alpha \varepsilon_r E_f V_{fr}}{(1 + e + V_{fr})}$$

$$\alpha = A_\alpha |\varepsilon_r|^{-B_\alpha}$$

Fig.A1: Concept of additional effective stress σ′f associated with fibre tension F (after Ajayi et al, 2017)

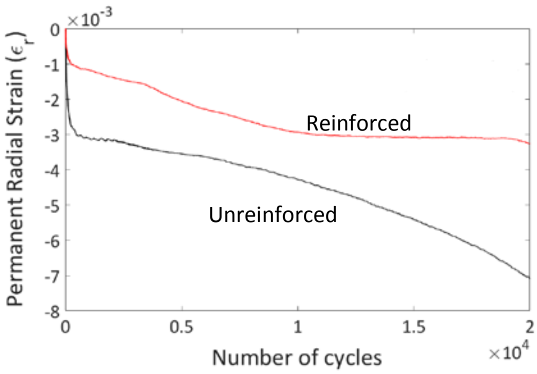


Fig.A2: Permanent radial strain vs no. of cycles for unreinforced and reinforced scaled ballast

Project aim 2. The conceptual framework described in [A1] was based on the behaviour of fibre reinforced scaled ballast (FRSB) in monotonic loading. In railway applications, the material will be subjected to cyclic loading at generally small strains. A programme of cyclic triaxial tests has therefore been carried out on specimens of $^1/_3$ and $^1/_5$ scale fibre reinforced ballast, to assess the behaviour of the material in cyclic loading. As an example of the results obtained, Fig. A2 shows the benefits of reinforcement in terms of reduced radial strain, over 2×10^4 cycles. The benefits of densifying the fibre reinforced material have also been demonstrated.

Project aim 3. Using the results of the cyclic triaxial tests, the conceptual framework described in [A1] is being extended to cover cyclic loading. The key finding is that, on unloading, axial strains hence increases in effective stress arising from fibre tension already developed may be assumed to remain locked in.

Project aim 4. Rig tests on full-scale fibre reinforced ballast [H18] have demonstrated the increased benefits of using narrower fibres, in terms of reducing plastic settlements over 3M loading cycles (Fig. A3). The reason for this – that the narrower fibres interfere less with the natural packing of the granular material, enabling placement at a greater bulk density/ smaller void ratio – is explained by the conceptual framework developed in [A1].

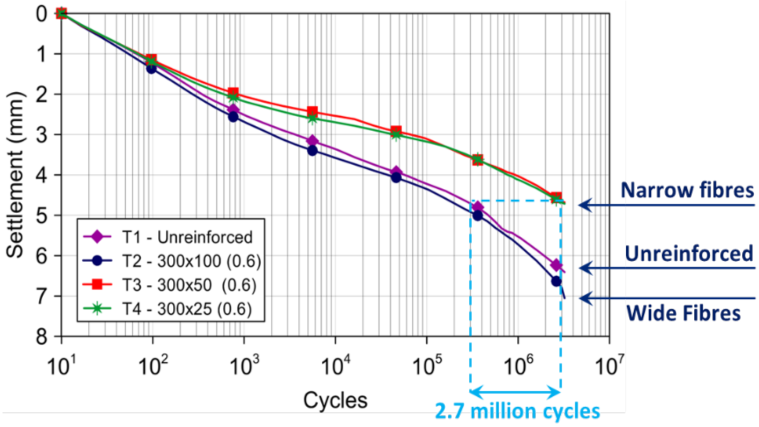


Fig.A3: Plastic settlement vs log no. of loading cycles for unreinforced and fibre reinforced ballasts in sleeper rig tests

Fig.A4: Field trial of FRB at Burnt Oak (LUL Northern Line)

Project aim 5. A method of field placement has been developed, and a 48 m-long trial section of FRB has been installed on London Underground's network at Burnt Oak (Northern Line: Fig. A4). Its short and long-term behaviour is currently being monitored, in terms of the track deflection as trains pass and permanent settlement / loss in geometry and how both develop with trafficking.

Planned further work (Programme objectives in brackets)

- Triaxial tests on full scale fresh, recycled, unreinforced and fibre reinforced ballast (1C.1)
- Refinement of the conceptual framework
- Consideration of non-plastics alternatives (e.g. natural fibres)
- Possible further rig tests and a second trial on LUL, maybe with recycled ballast (1C.2)
- Use of data to optimise track system performance (1A.4)
- Incorporation of results into integrated performance and maintenance models (1A.5)

Journal papers

[A1] Ajayi, O O, Le Pen, L, Zervos, A & Powrie, W. (2016). A behavioural framework for fibre reinforced gravel. *Géotechnique* **67** No.1, 56-68. doi:10.1680/jgeot.16.P.023
[A2] Ajayi, O O, Le Pen, L, Zervos, A & Powrie, W. (2017). Scaling relationships for strip fibre reinforced aggregates. *Canadian Geotechnical Journal* **54** No.5, 710-719. doi:10.1139/cgj-2016-0346.

Related publications

[H18] Ferro, E, Ajayi, O, Le Pen, L, Zervos, A, & Powrie, W (2016). *Settlement response of fibre reinforced railway ballast. Paper presented at 11th World Congress on Railway Research. (WCRR2016), Italy.*
Powrie, W and Le Pen, L (2017) Article, "Ballasted Rail Track: reducing maintenance needs." *Rail Technology Magazine Oct/Nov 2017 (pp84f)*