UNIVERSITY OF Southampton
Engineering and the Environment

25th ALERT Workshop

Reinforcement of railway ballast using random fibre inclusions

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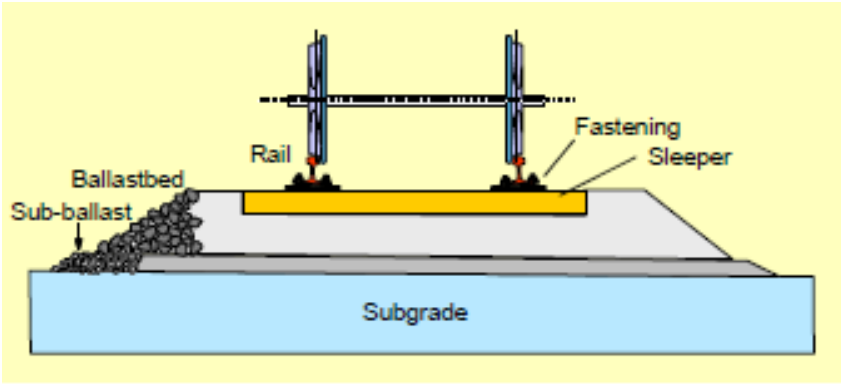
Louis Le Pen, Antonis Zervos & William Powrie

TRACK 21 railway track for the 21st century EPSRC

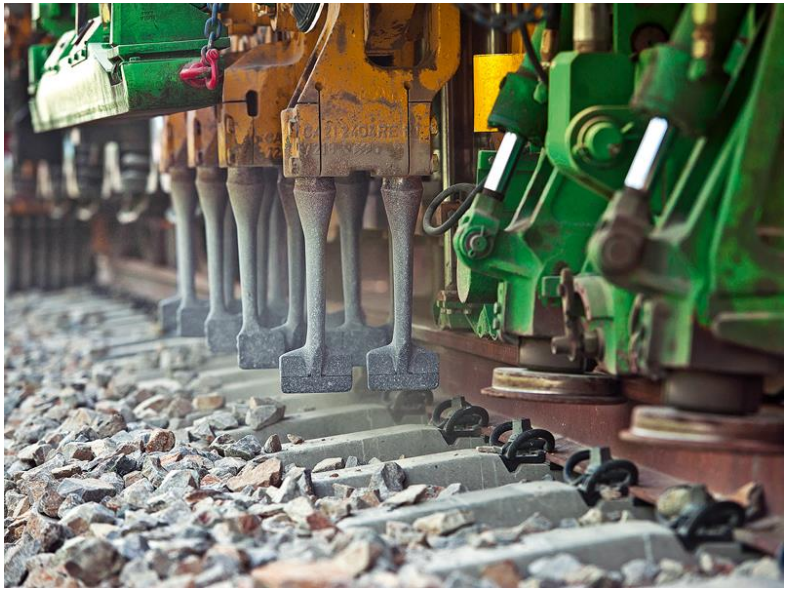
NetworkRail



Ballast in the sub-structure:

- Reduces bearing pressure on underlying foundation soil
- Retains track alignment

→ Track settlement



Tamping:

- To restore line and level
- Performed periodically
- Causes ballast breakage

Geogrids:

- To reduce permanent vertical settlement and lateral spread
- Limitations on tamping

- Faster and more frequent trains
- Railway's working day is becoming longer
- Renewals and maintenance cost

Track materials:

- More resilient
- Cost effective

Fibres

D_{50} = 1.8 mm

Fibre reinforced LB sand

e.g. Michalowski & Zhao (1996); Diambra et al. (2010); Dos Santos et al. (2010)

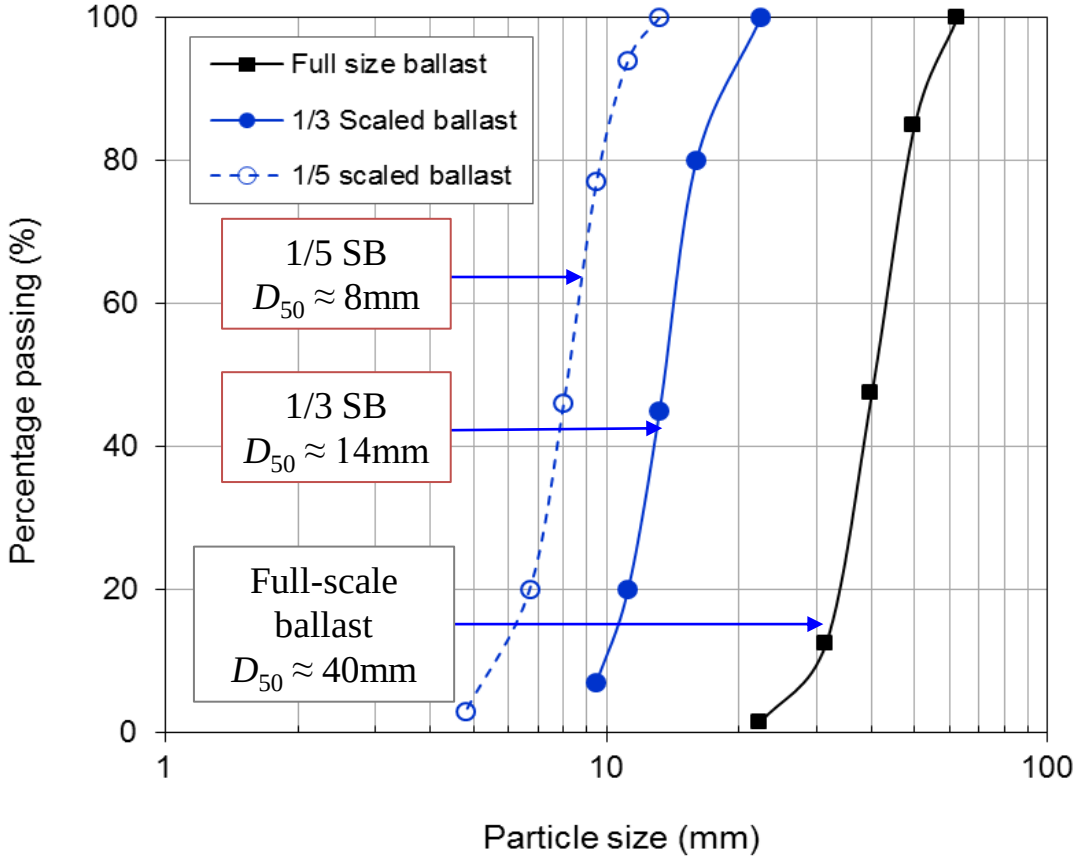
D_{50} = 42 mm

Fibre reinforced ballast

- Influence of fibres on packing of larger aggregates
- Scaling relationships
- Mechanical behaviour in railway ballast

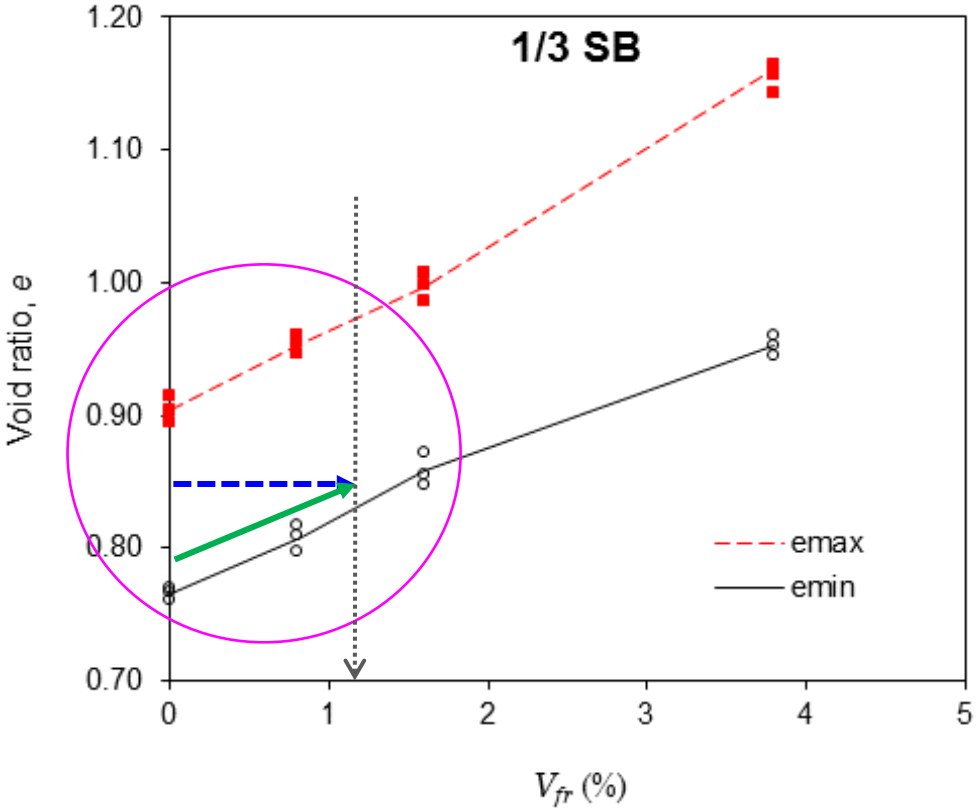
Outline

- Develop a framework for the effects of fibre reinforcements on the packing of large aggregates
- Evaluate the mechanical properties and scaling relationships of fibre reinforced scaled ballast
  - Triaxial tests
  - Image-based deformation measurements
- Full-scale laboratory tests using single sleeper tests



Polyethylene fibres

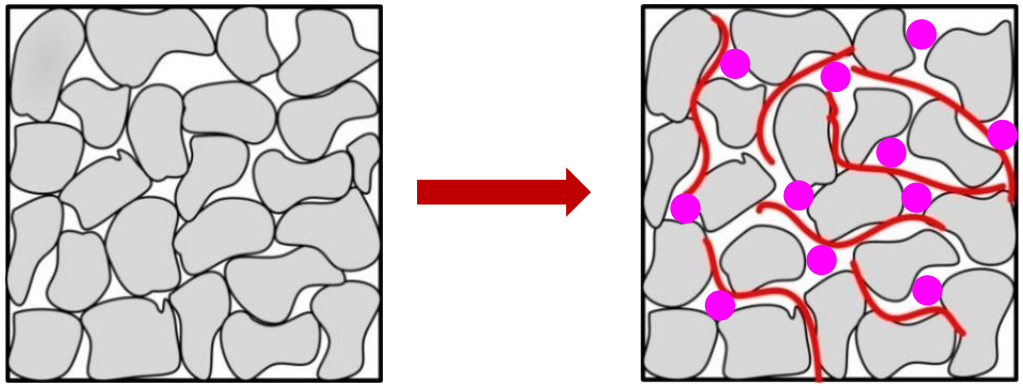
- Scaled ballast use in railway ballast research validated (Le Pen et al. 2013; Sevi 2008)
- Used in railway research (e.g. Sevi et al. 2009; Ishikawa et al. 2011; and Le Pen et al. 2014)



- Volumetric fibre ratio, $V_{fr} = \frac{V_f}{Vs}$
- Void ratio, $e = \frac{V_v}{V_s}$

after Ajayi et al. (2014)

- Varying V_{fr} at constant void ratio will produce different relative densities



Unreinforced ballast
@ constant V_T

Fibre reinforced ballast
@ constant V_T

- V_s decreases
- V_v increases

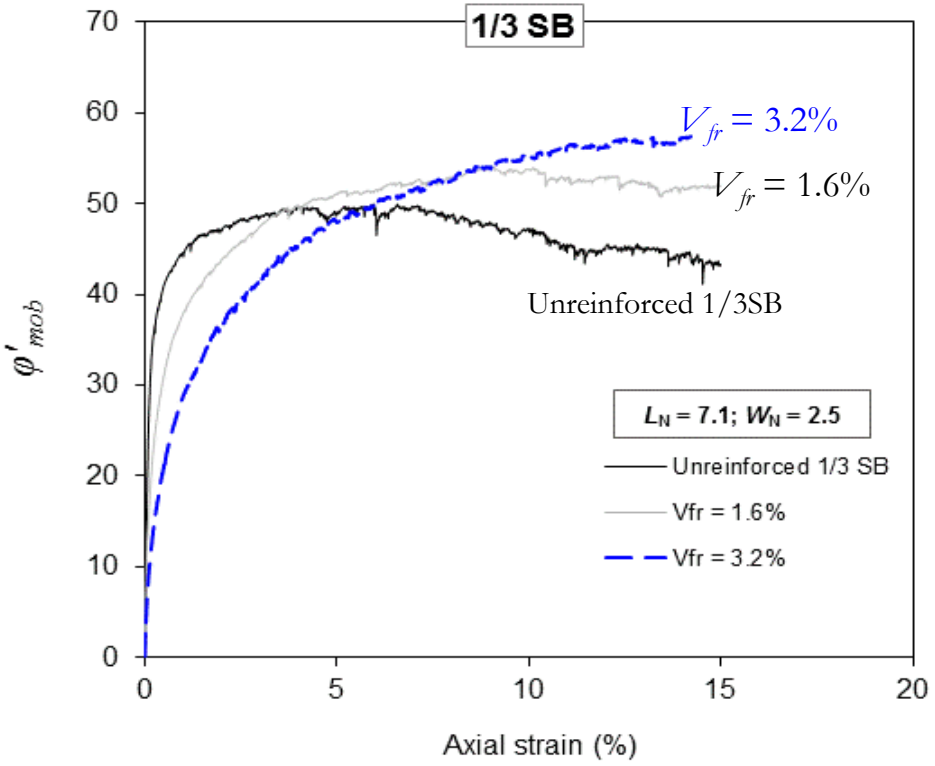
- Indication of the behaviour of the constituents of the mixture when fibres are introduced

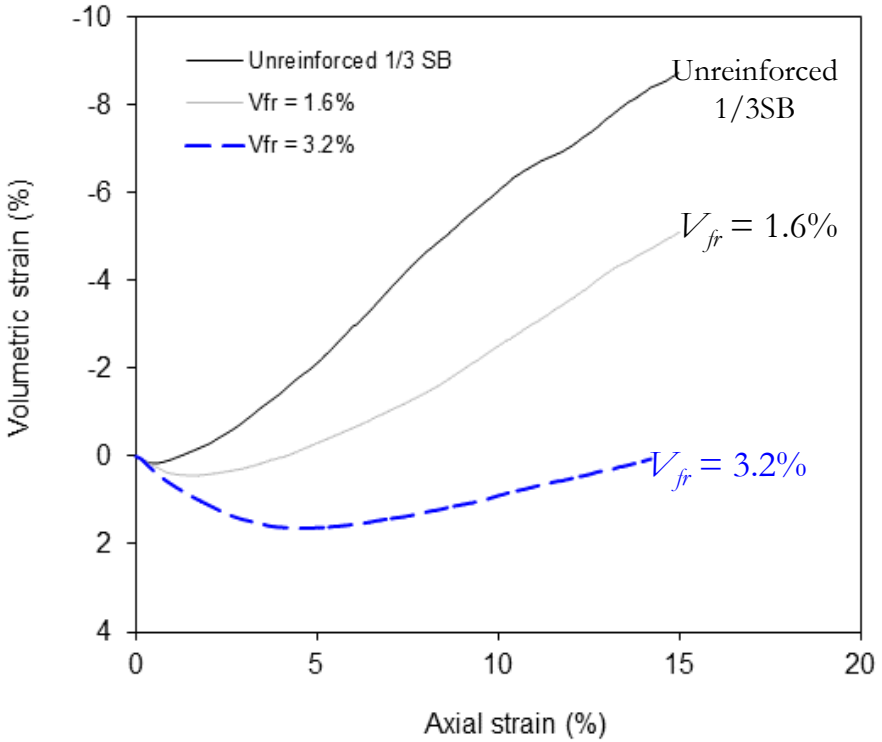
- Confining stress = 30 kPa
- Monotonic loading
- ~ e_{min} (at constant relative density)

Parameters:

- V_{fr}
- $L_N = \frac{L_f}{D_{50}}$
- $W_N = \frac{W_f}{D_{50}}$

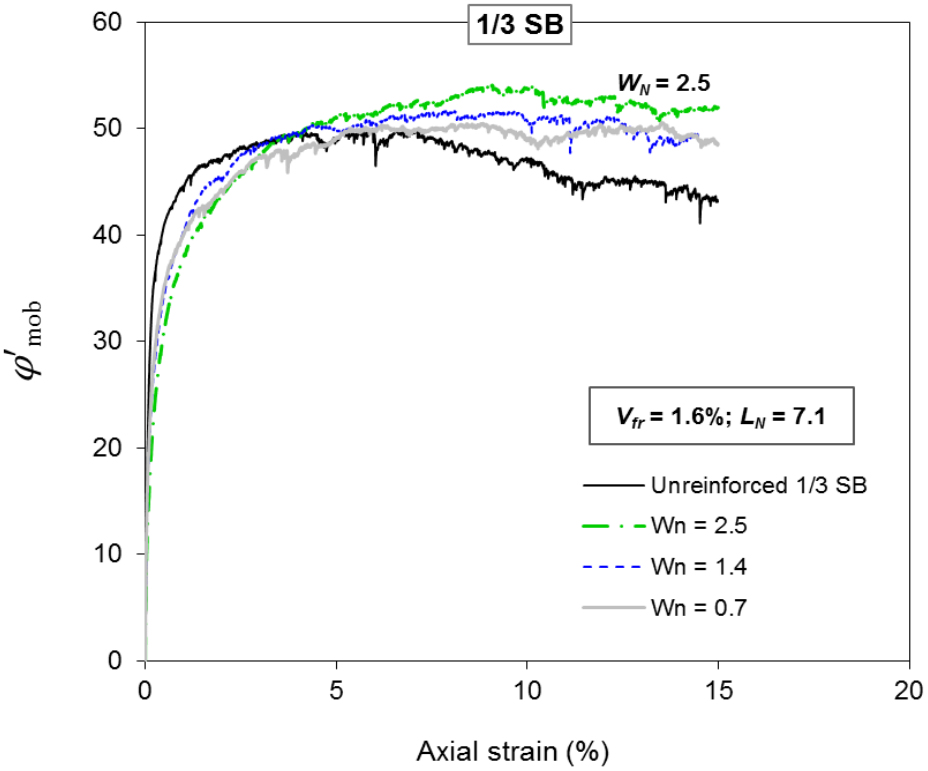
Constant L_N and W_N

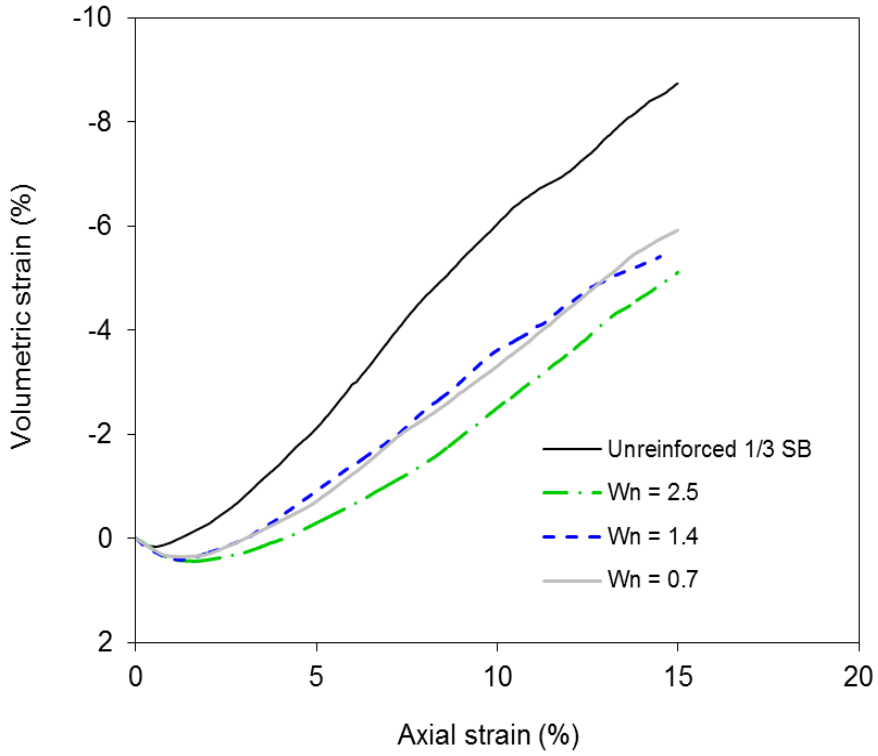




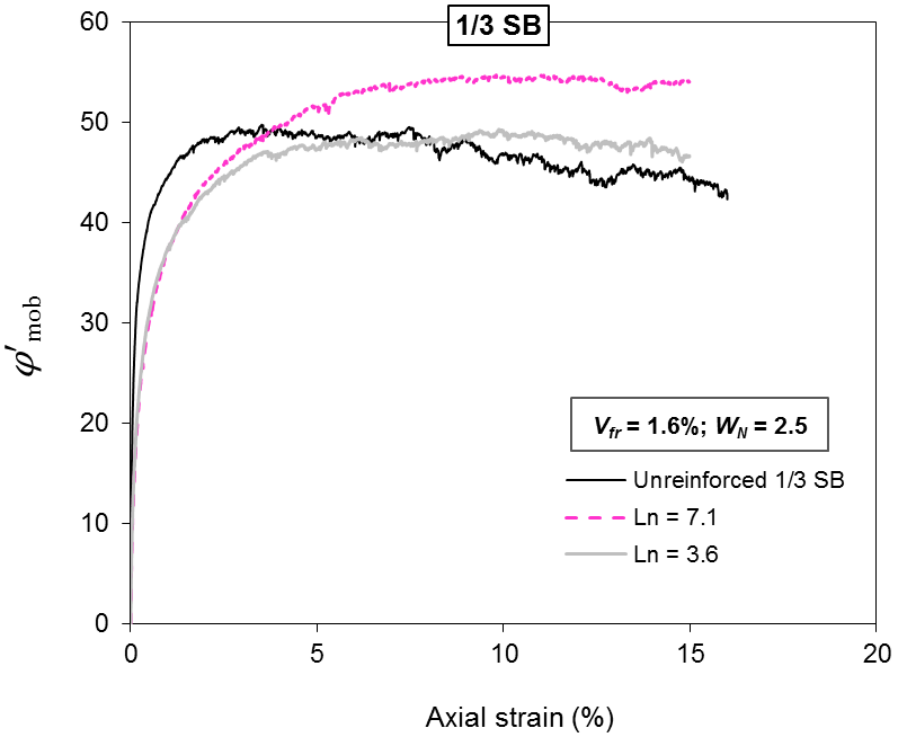
- More ductile
- Reduced initial stiffness
- Suppressed dilation

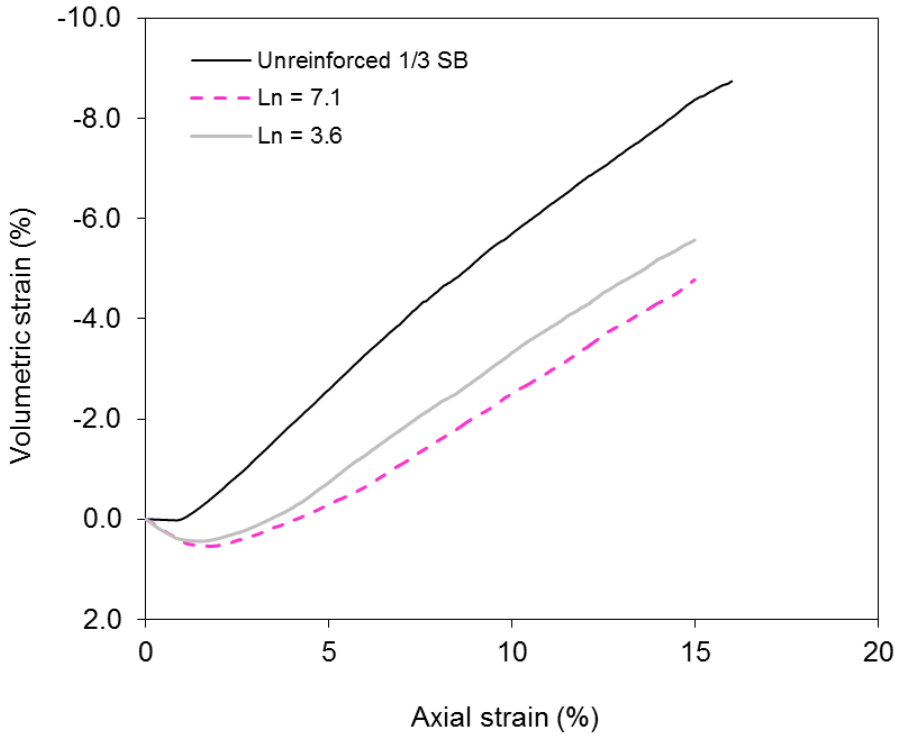
Constant V_{fr} and L_N





Constant V_{fr} and W_N





- L_N and W_N both influence mobilised strength.
- At large strains, the influence of L_N on the mobilised strength is more prominent than W_N

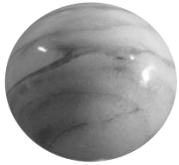
Scaling relationships

$D_{50} \sim 8mm$

Scaling relationships

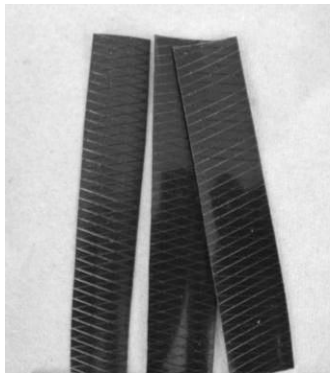
$D_{50} \sim 42mm$

≈



Particle, D_{50} Sphere, D_{50}

Avg. no. of particles, N_p

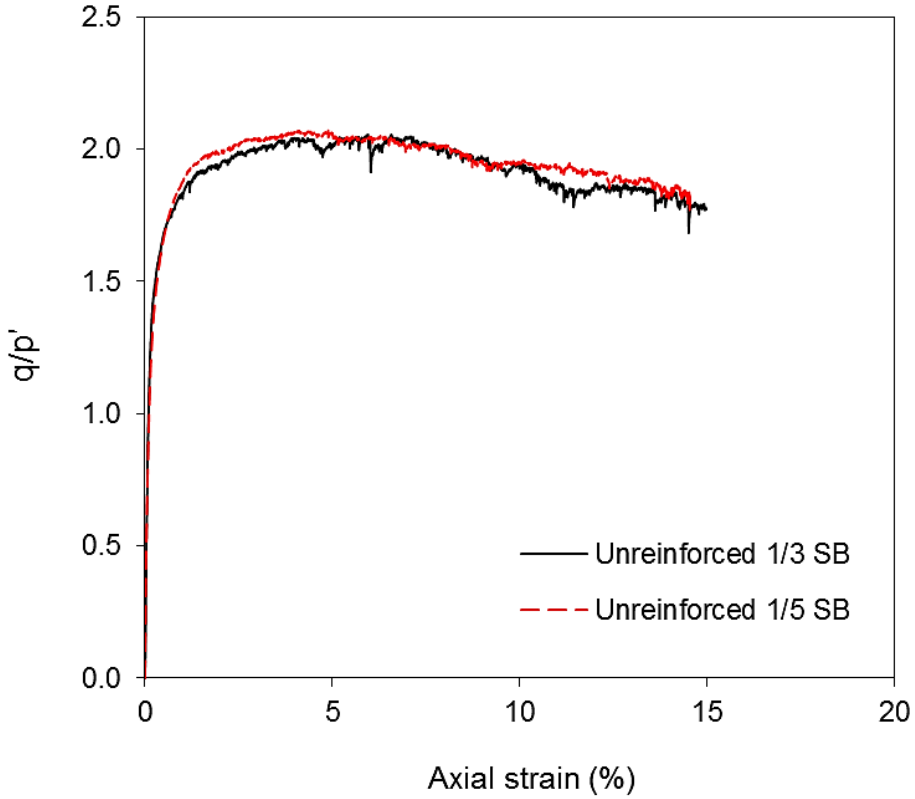


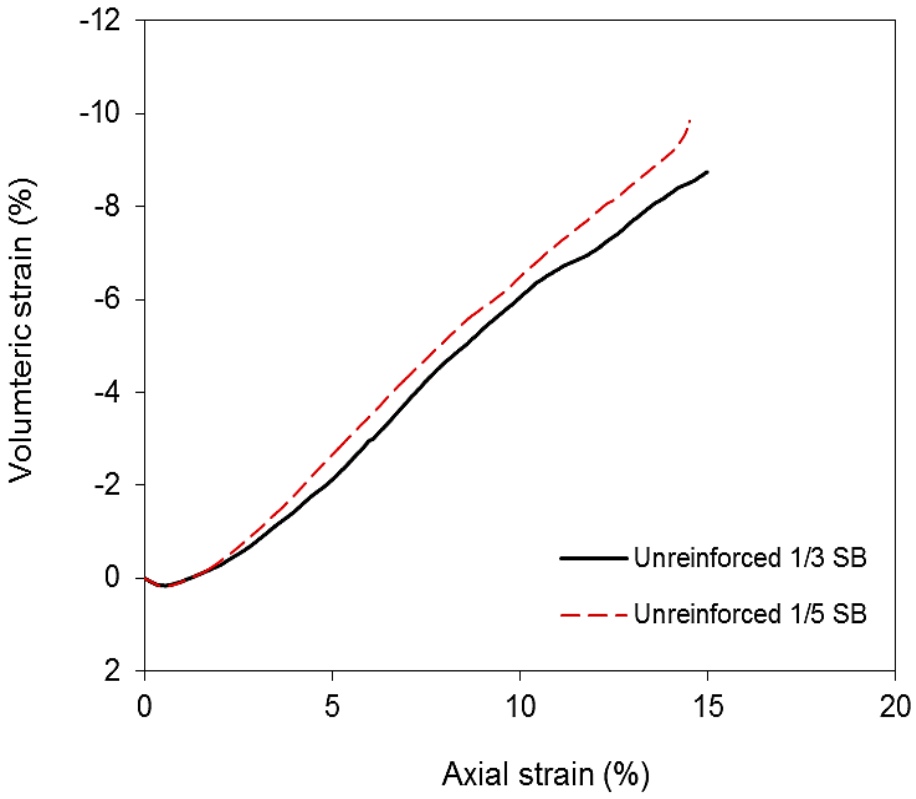
Fibres, N_f

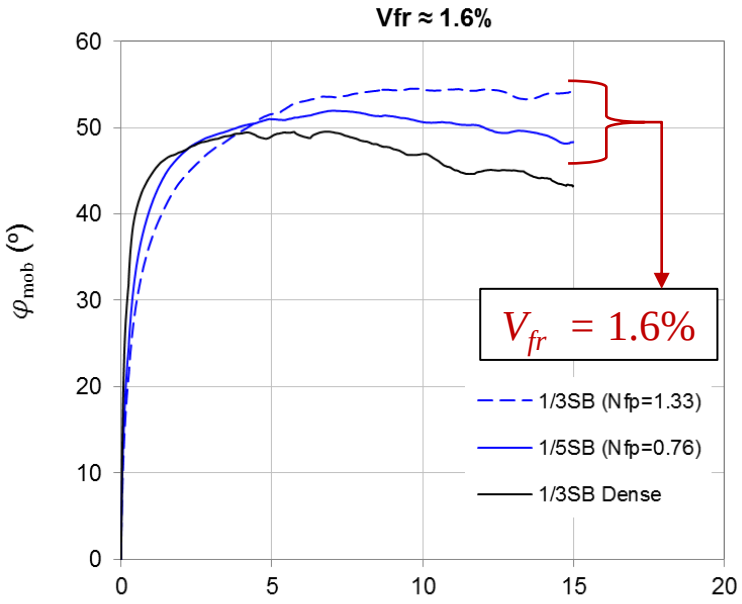
$$N_{fp} = \frac{N_f}{N_p}$$

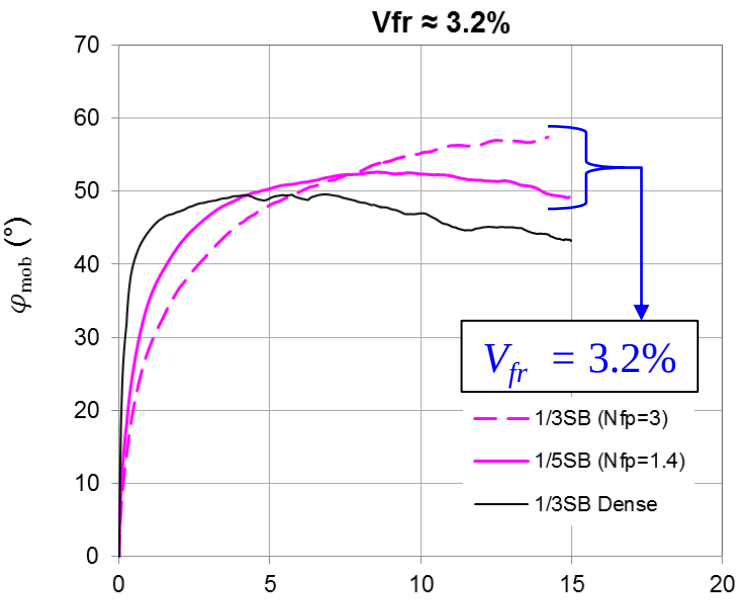
No bending stiffness: fibre thickness ignored

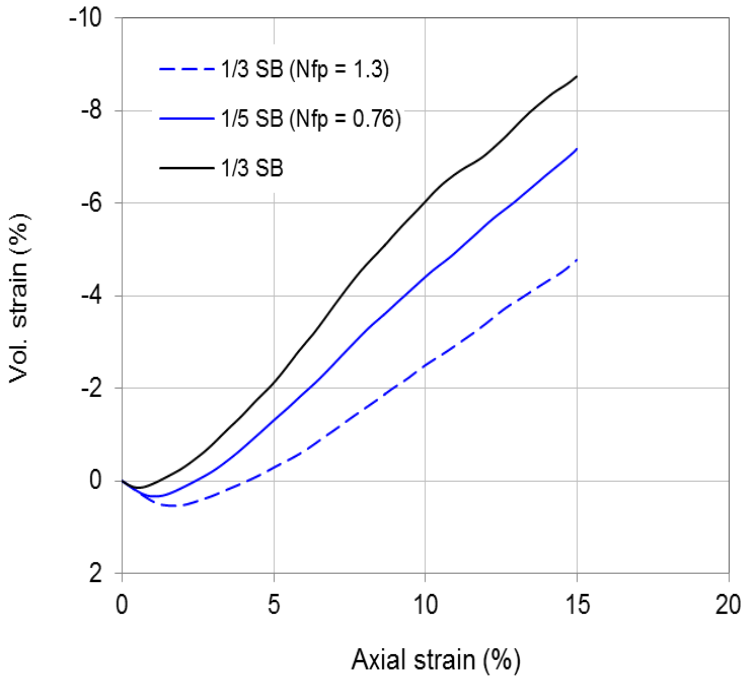
Comparing 1/5th and 1/3rd scaled ballast

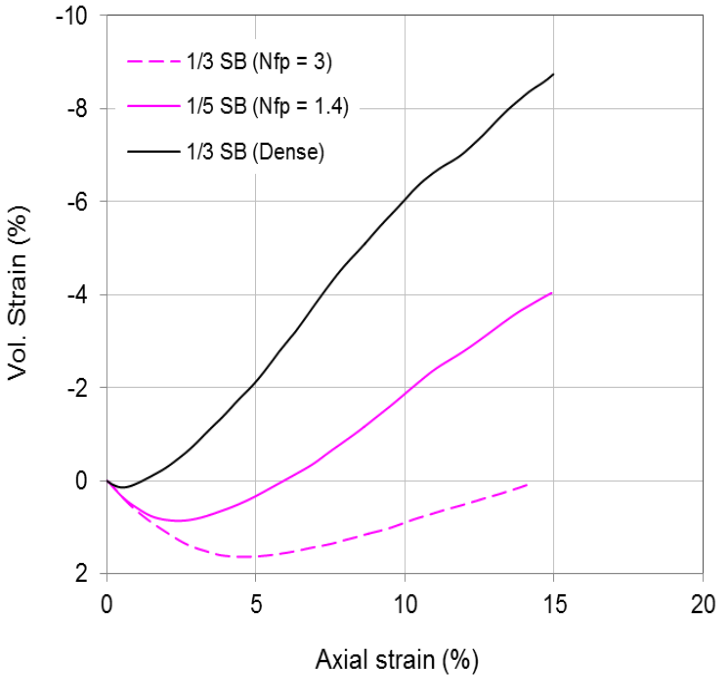


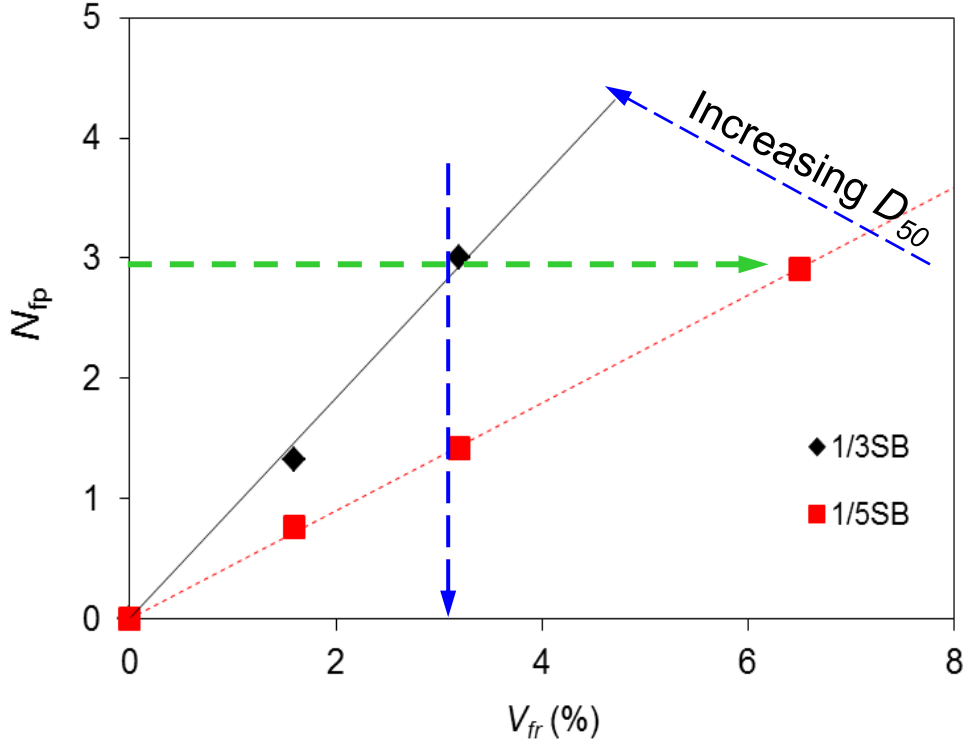


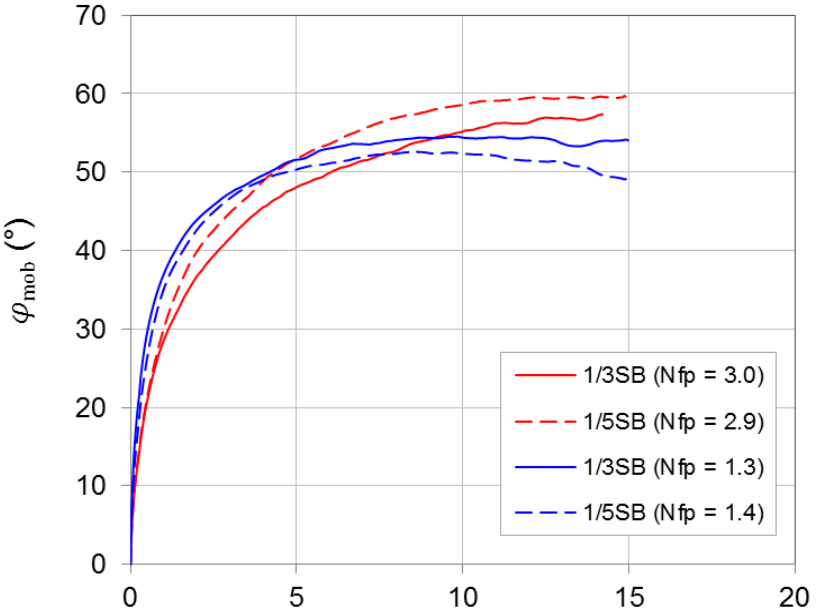

Vfr ≈ 1.6%
φ_{mob} (°)
V_{fr} = 1.6%
1/3SB (Nfp=1.33)
1/5SB (Nfp=0.76)
1/3SB Dense

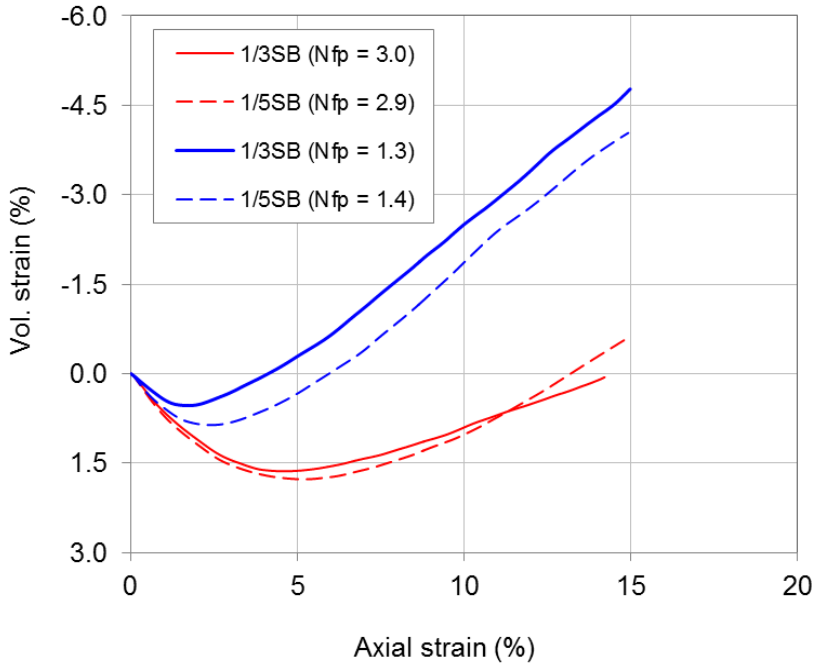

Vfr ≈ 3.2%
φ_{mob} (°)
V_{fr} = 3.2%
1/3SB (Nfp=3)
1/5SB (Nfp=1.4)
1/3SB Dense


Vol. strain (%)
1/3 SB (Nfp = 1.3)
1/5 SB (Nfp = 0.76)
1/3 SB
Axial strain (%)


Vol. Strain (%)
1/3 SB (Nfp = 3)
1/5 SB (Nfp = 1.4)
1/3 SB (Dense)
Axial strain (%)

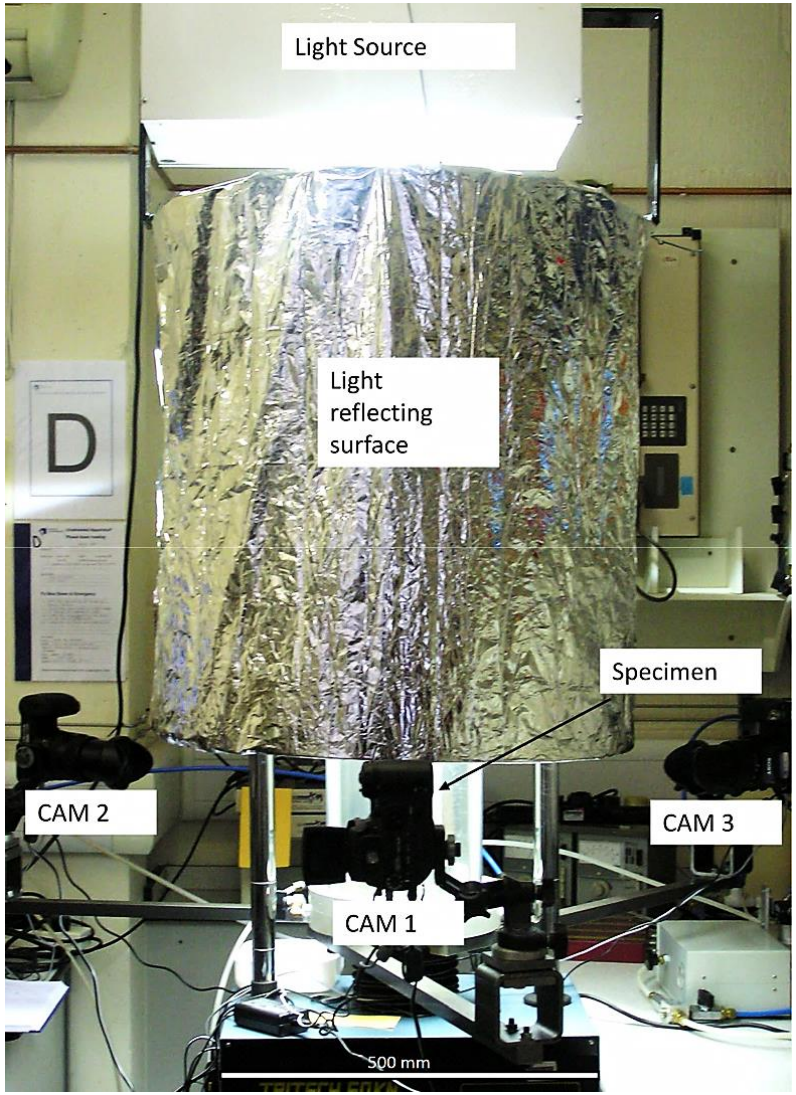






- N_{fp} is important when considering fibre/particle interactions over different particle size ranges

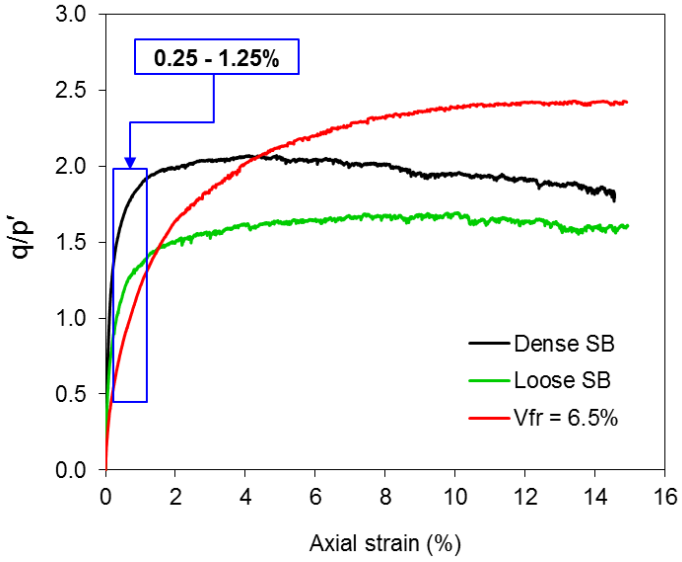
  * if fibre thickness is not considered



Triax-Digital Image Correlation (Bhandari et al., 2012)

Measurement grids on triaxial specimen

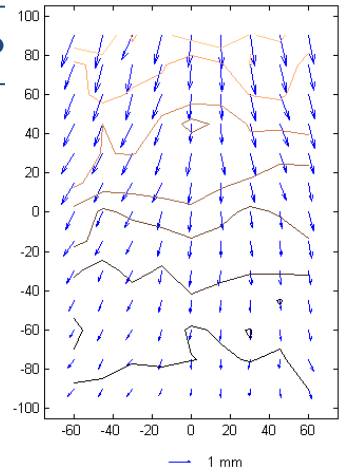
Pre-peak deformation

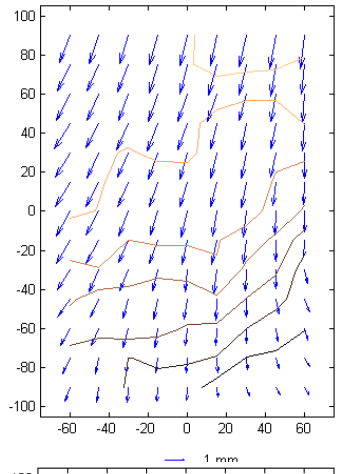


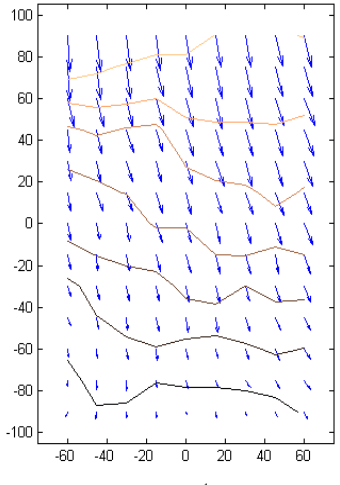
Unreinforced **Dense** SB

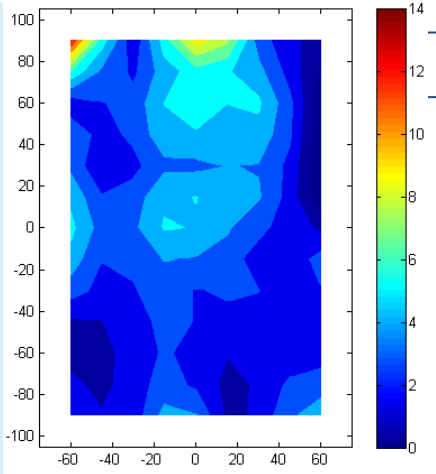
Unreinforced **Loose** SB

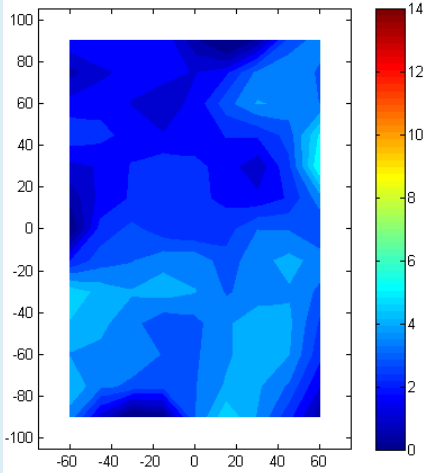
V_{fr} = 6.5%

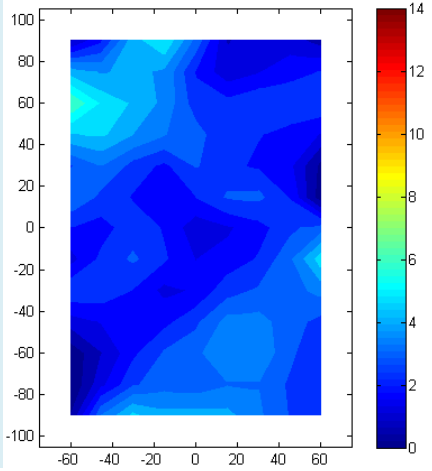






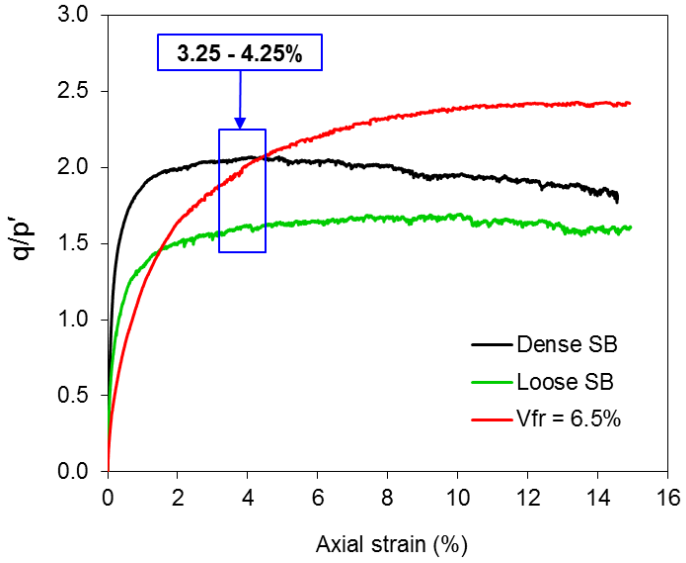






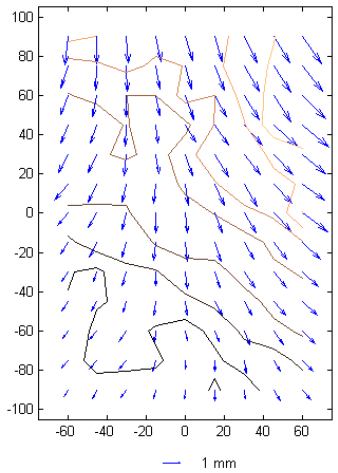
Maximum shear strain (%)

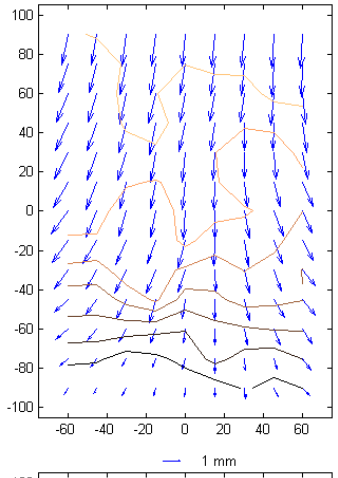
Pre-peak deformation

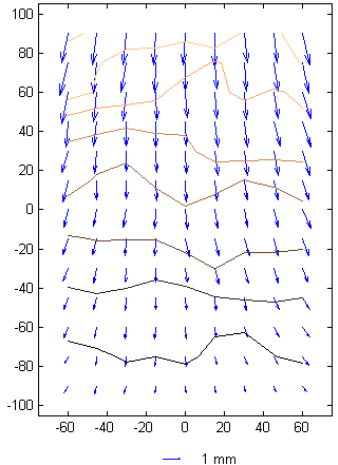


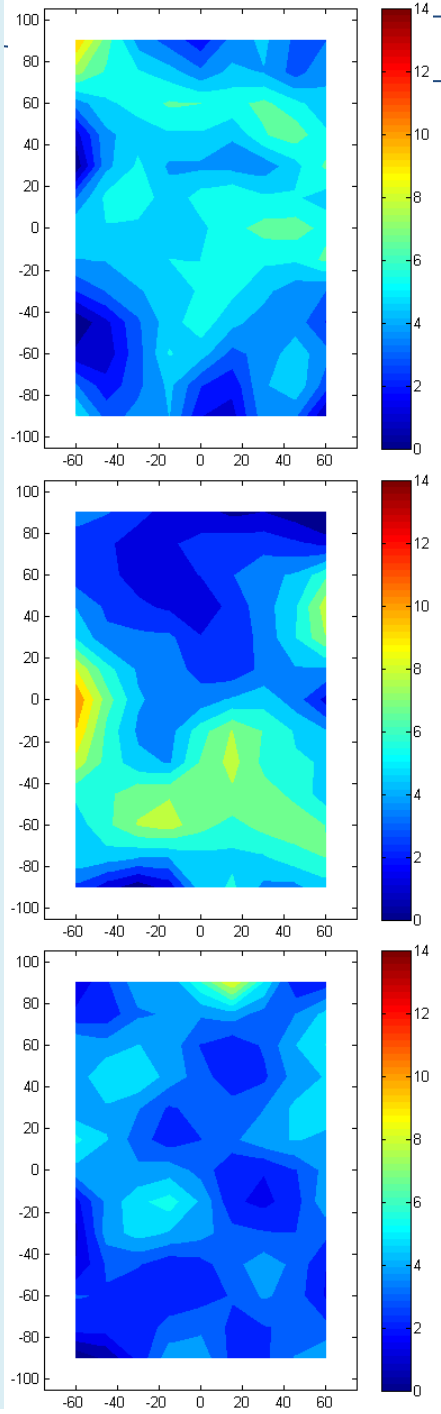
Unreinforced **Dense** SB

Unreinforced **Loose** SB





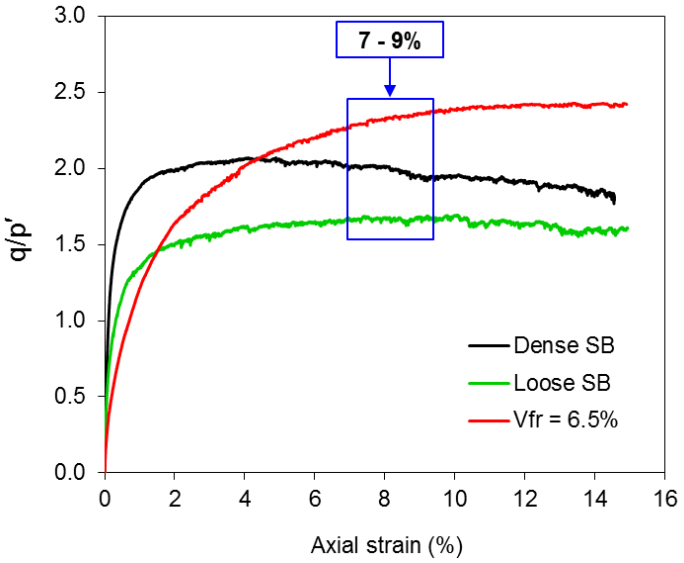




- More uniform vertical deformation in reinforced specimens (i.e. smaller horizontal deformation)
- Smaller and more uniform shear strains in reinforced specimens

$V_{fr} = 6.5\%$

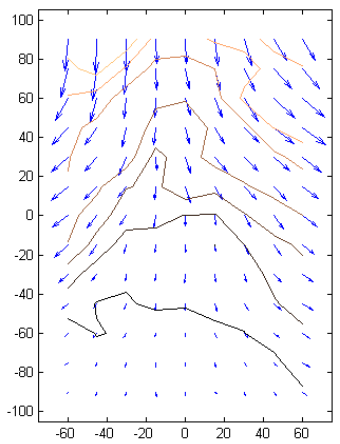
Post-peak deformation

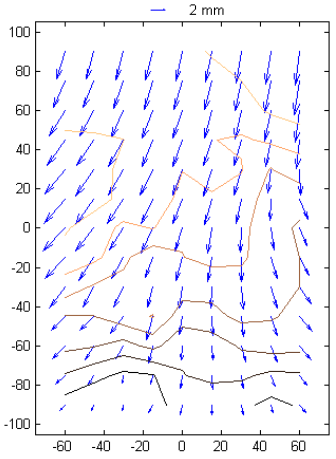


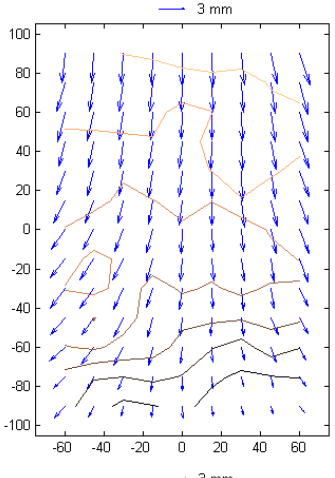
Unreinforced **Dense** SB

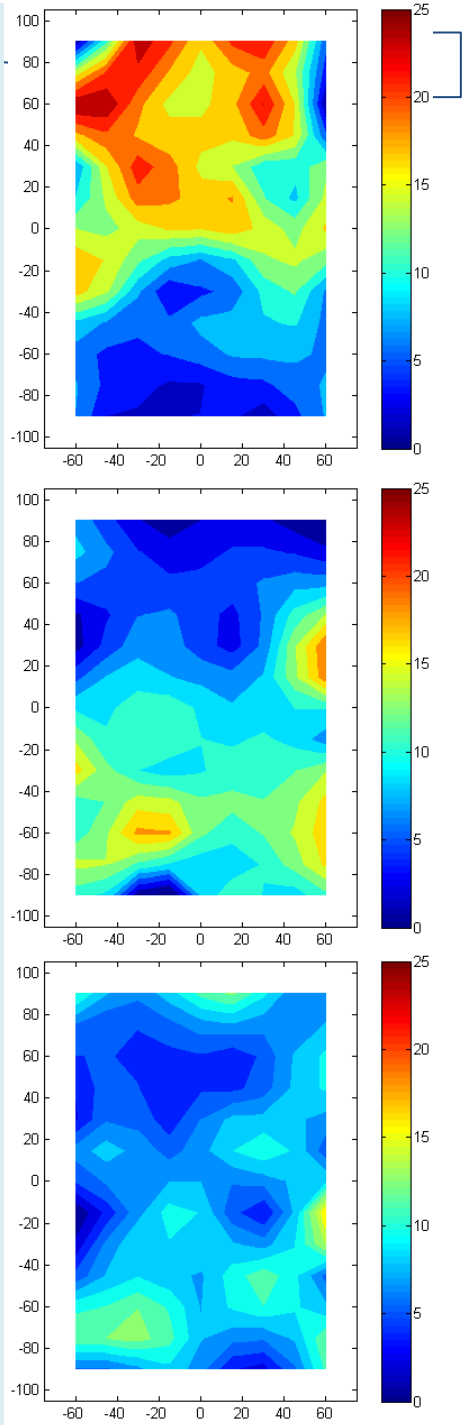
Unreinforced **Loose** SB

V_{fr} = 6.5%

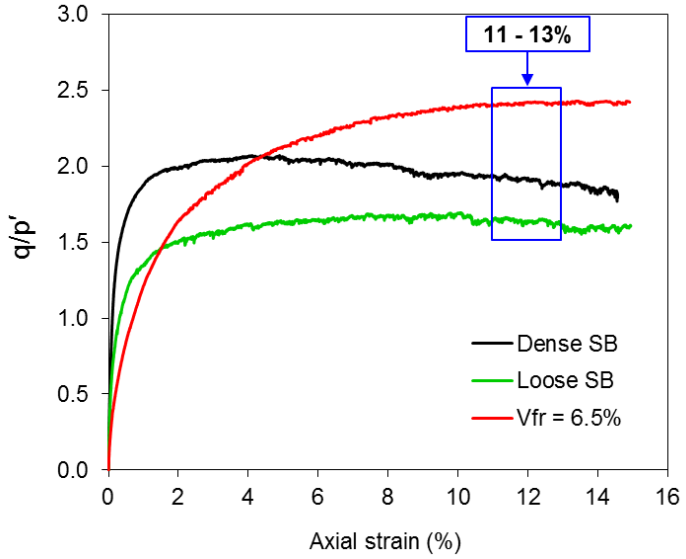








Post-peak deformation

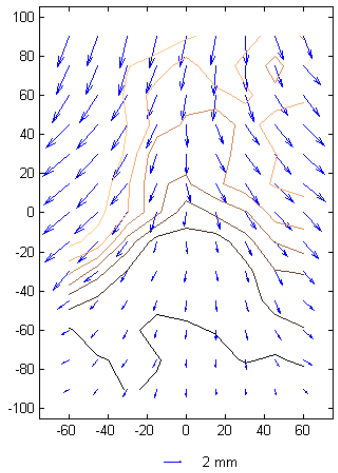


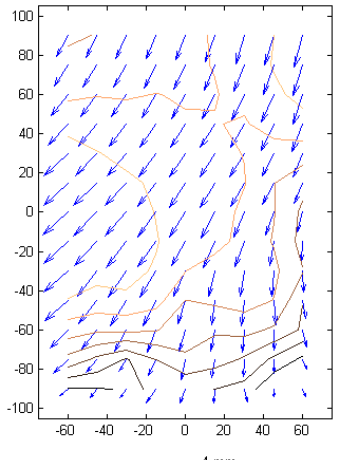
Unreinforced **Dense** SB

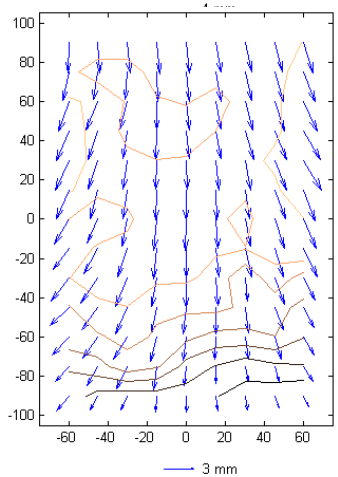
Unreinforced **Loose** SB

- More homogeneous shear strains in reinforced specimen. Probably due to the reinforcing effect of fibres
- Strain localisation probably evident in bulging deformation and “V” contour shape

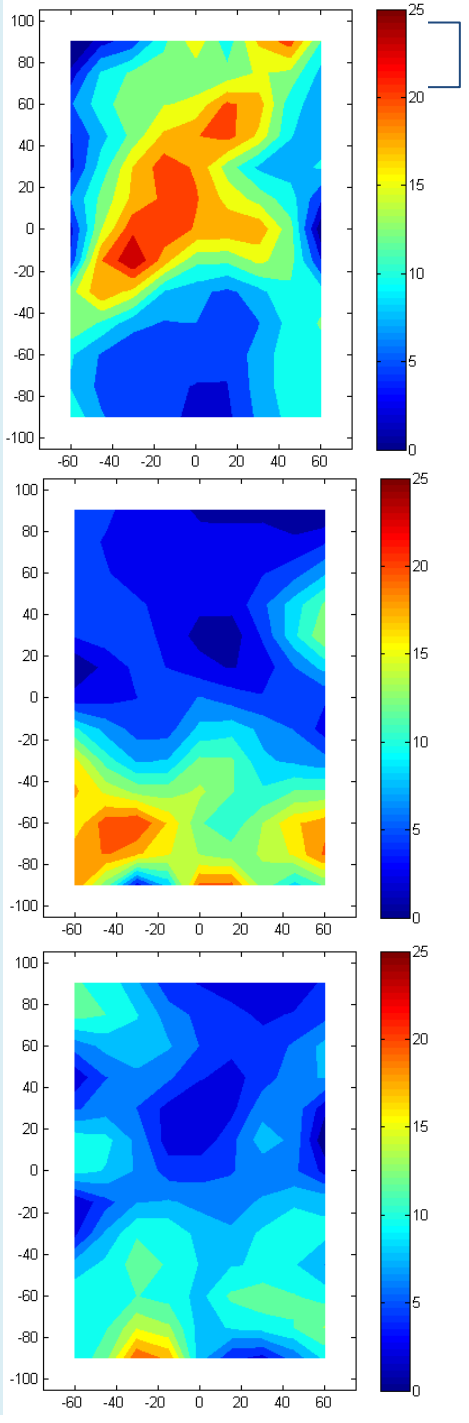
$V_{fr} = 6.5\%$



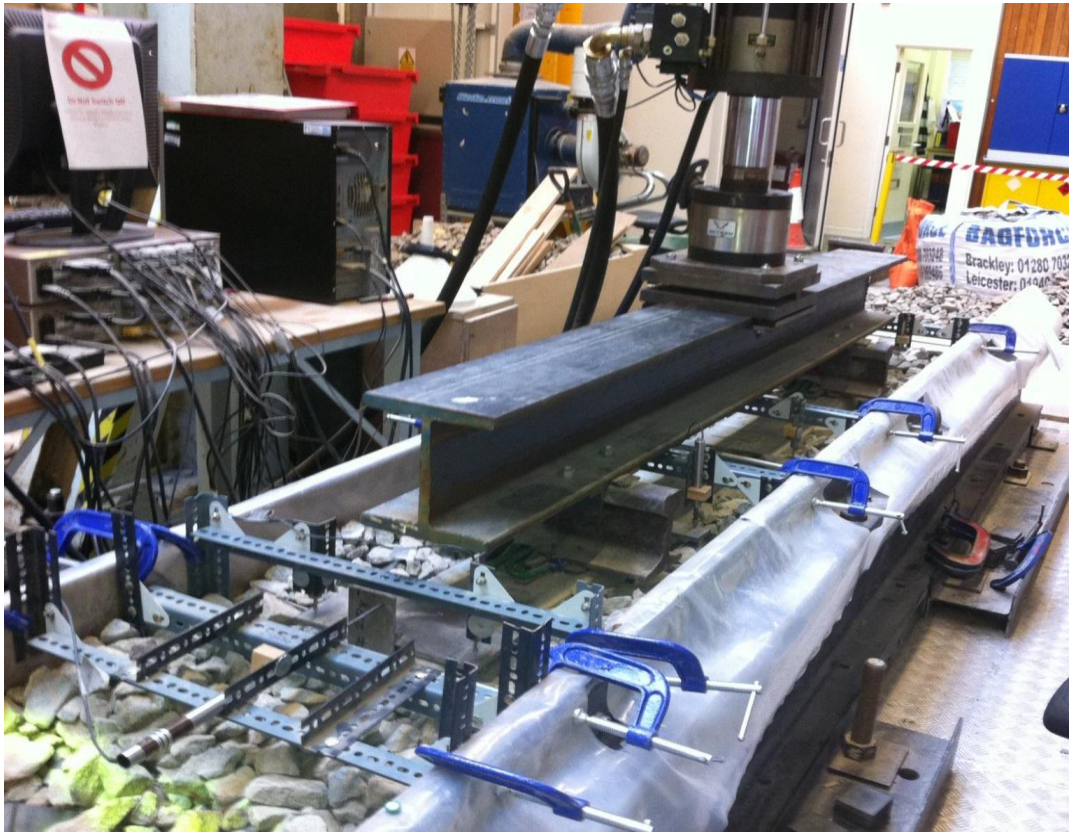




Maximum shear strain (%)

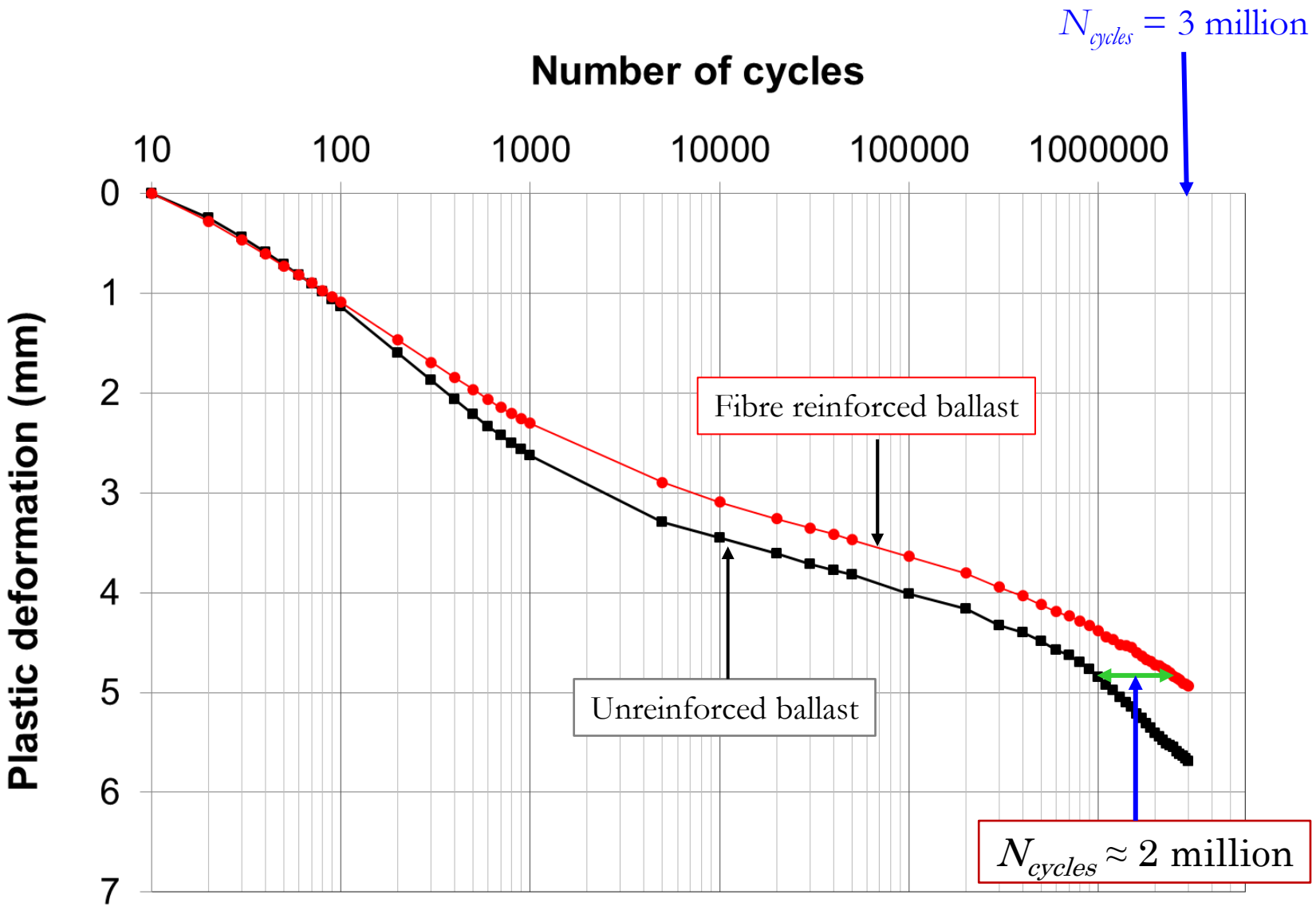


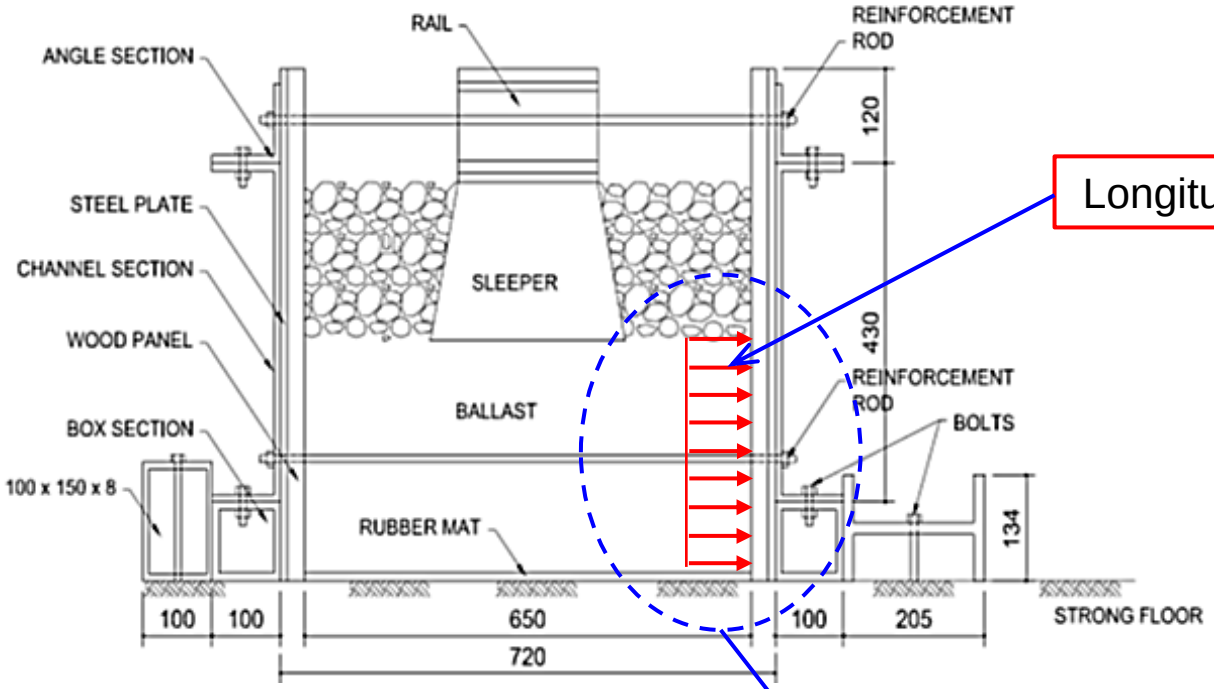
L_N = 7.5 W_N = 2.5 N_{fp} = 1.33 (V_{fr} ≈ 0.6%)



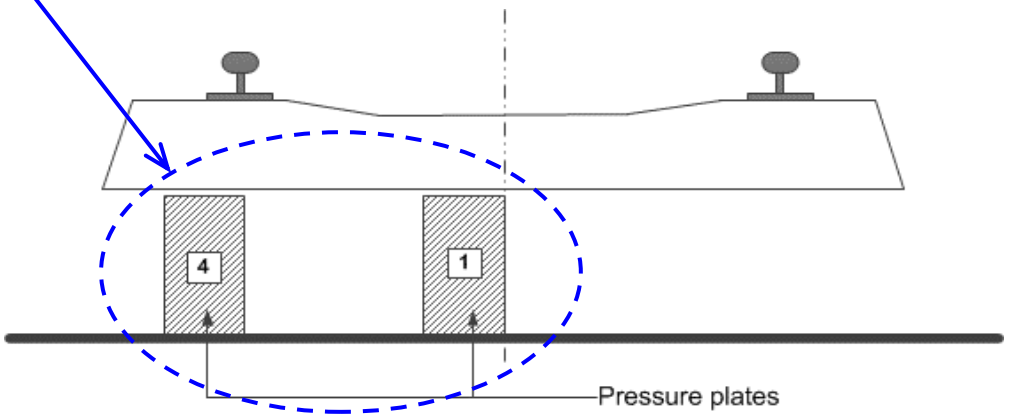
Southampton Railway Test Facility

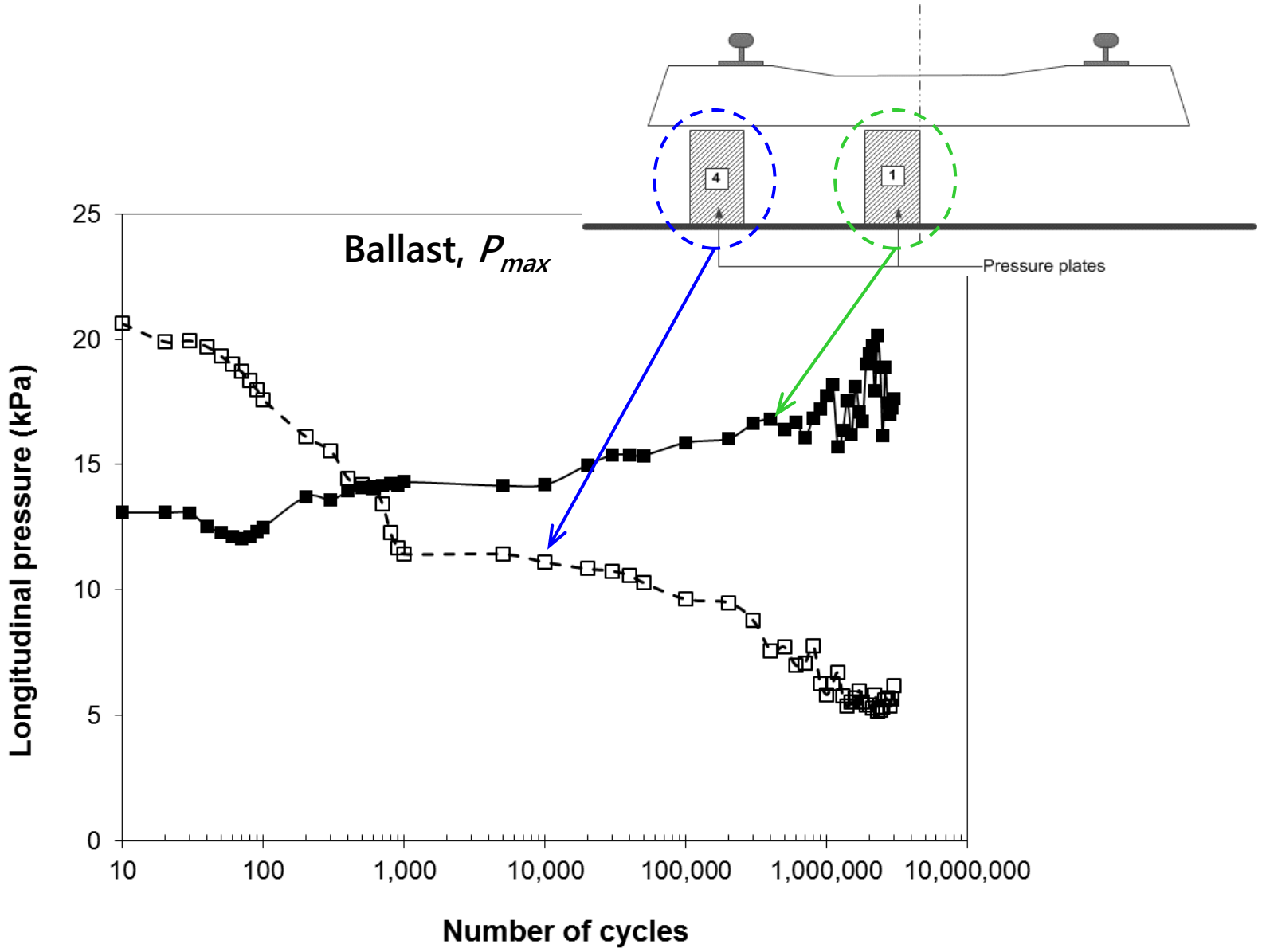
Fibre reinforced ballast

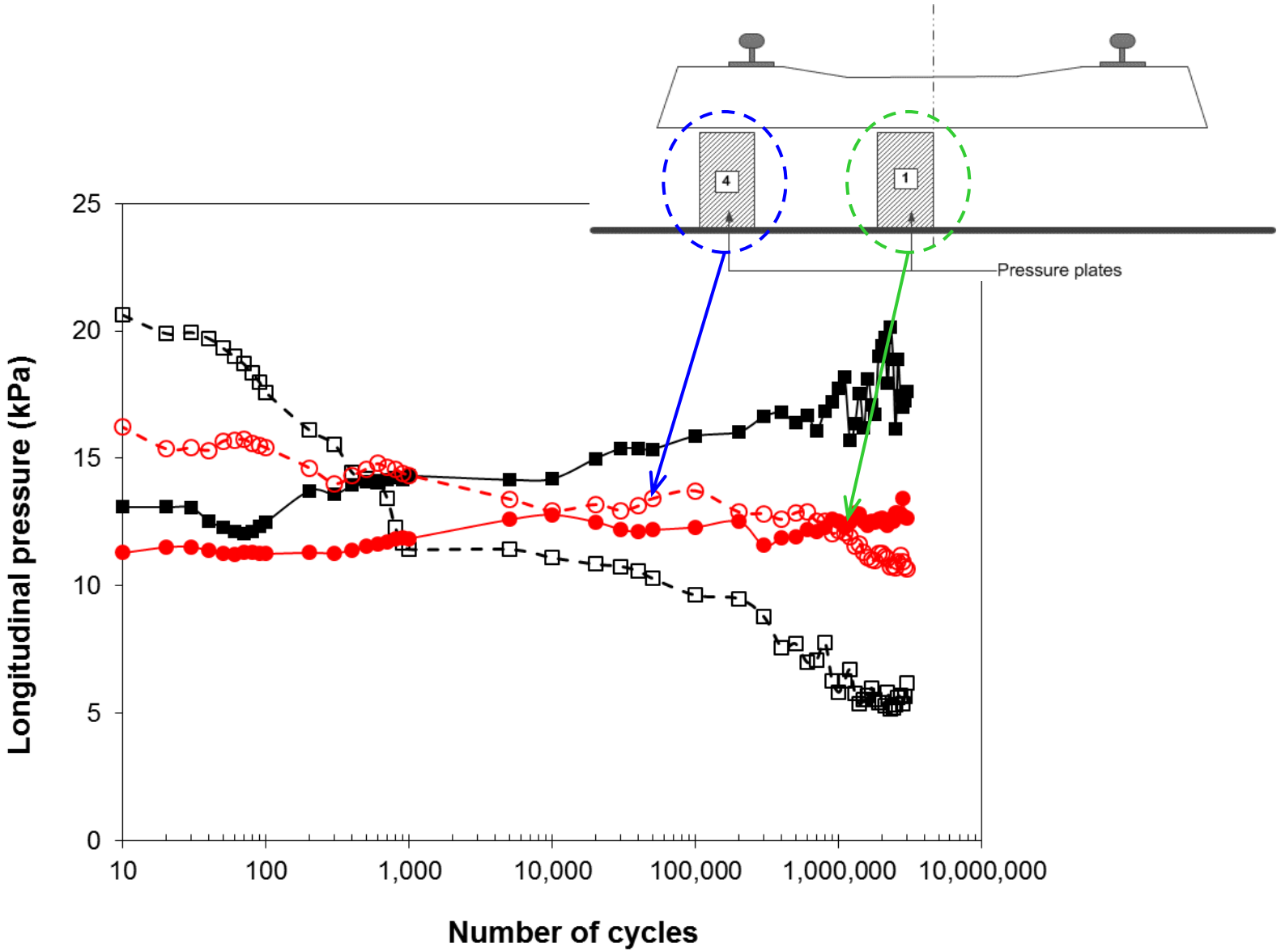

N_{cycles} = 3 million
Number of cycles
10
100
1000
10000
100000
1000000
Plastic deformation (mm)
0
1
2
3
4
5
6
7
Fibre reinforced ballast
Unreinforced ballast
$N_{cycles} \approx$ 2 million



Longitudinal pressure, *P*




Ballast, P_{max}
4
1
Pressure plates
Longitudinal pressure (kPa)
25
20
15
10
5
0
10
100
1,000
10,000
100,000
1,000,000
10,000,000
Number of cycles


4
1
Pressure plates
Longitudinal pressure (kPa)
25
20
15
10
5
0
10
100
1,000
10,000
100,000
1,000,000
10,000,000
Number of cycles

Summary

- Addition of fibres to large aggregates increases e_{min} and e_{max} as fibre content (V_{fr}) increases
- Observations from triaxial tests on fibre reinforced scaled ballast
  - Increases ductility
  - Delays dilation
  - Influenced by V_{fr}, L_N, W_N and N_{fp} when considering different particle sizes
  - Produces a more uniformly vertical deformation and homogeneous distribution of shear strain
- Observations from full-scale lab. tests on fibre reinforced railway ballast
  - Reducing plastic settlement
  - More even distribution of longitudinal stresses

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Engineering and the Environment

Thank you for your attention

Any questions??

EPSRC

TRACK 21

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