State-of-the-art design aspects of ballasted rail tracks incorporating particle breakage, fouling, and the benefits of geosynthetic reinforcement

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STATE-OF-THE-ART DESIGN ASPECTS OF BALLASTED RAIL TRACKS INCORPORATING PARTICLE BREAKAGE, FOULING, AND THE BENEFITS OF GEOSYNTHETIC REINFORCEMENT

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SUMMARY

Railways are expected to be the main mode of future transport in Australia, and its large network should provide the essential needs for the quick and safe mobility of both freight and commuters. In spite of recent advances in rail track geotechnology, the optimum choice of ballast for track design is still considered critical because aggregates progressively degrade under heavy cyclic loading. Ballast degradation is influenced by various factors, including the amplitude and number of load cycles, particle gradation, confining pressure, and the angularity and fracture strength of individual grains. The relationship between the size of the geogrid aperture and the shear strength of the ballast-geogrid interface was obtained using large scale direct shear tests. The role of ’Void Contaminant Index’ (VCI) to improve the assessment of fouling compared to other mass based indices is discussed. A series of large scale hydraulic conductivity tests were conducted on fouled ballast with varying VCI to establish a relationship between the extent of fouling and associated hydraulic conductivity. The stress-strain behaviour of coal-fouled ballast with and without geogrid reinforcement was studied using a large scale direct shear apparatus. The outcomes of this research are now elucidated in view of industry practices.

1. INTRODUCTION

In Australia, the railway system plays a significant role in bulk freight and passenger transport. The rail track substructure is divided into four major parts, namely ballast, subballast (capping), structural fill, and subgrade. Ballast forms the load bearing layer upon which railway sleepers (UK) or railroad ties (USA) are laid. The engineering behaviour of ballast is one of the most important aspects governing the stability and performance of railway track. Although ballast consists of strong and tough aggregates (high quality igneous or metamorphic rock fragments), these aggregates still progressively deform and deteriorate under repeated heavy train (cyclic) loading and contribute to over 50% of the total deformation of railway tracks [1,2,3]. The crushed rock fines (due to particle breakage), coal fines (due to spillage from coal wagons) and clay-silt fines (due to pumping of soft saturated subgrade) accumulate within the voids (i.e. fouling) of the ballast bed and impair track drainage. The routine replenishment of fouled ballast creates serious concerns for the Environmental Protection Authority (EPA), in addition to high disposal costs. In order to improve track conditions and reduce the cost of maintenance, the use of geosynthetic grids can be beneficial. Alternatively, if the waste ballast is cleaned, sieved, and then re-used in track...
reinforced with geosynthetics, it is also an economically feasible option.

Around 76% of ballast fouling originates from the fracture and abrasion of ballast particles, followed by 13% of infiltration from subballast, 7% infiltration from surface ballast, 3% from subgrade intrusion, and 1% from sleeper wear [4,5]. However, in Australia, the intrusion of coal fines and ballast breakage are the major sources of ballast fouling and contribute from 70-95% and 5-30% of ballast fouling respectively [6]. In order to understand the effects of fouling on drainage conditions, a series of large scale constant head hydraulic conductivity tests were conducted to establish the relationship between the VCI and the associated hydraulic conductivity [7].

The use of geosynthetics for drainage and internal track confinement, and as separation layer between the ballast and subballast, is highly desirable [8,9]. The results of large-scale cyclic tri-axial drained tests on fresh and recycled ballast with geosynthetics indicated that a layer of geocomposite (bi-axial geogrid bonded with non-woven geotextiles) stabilised recycled ballast much better than standard geogrids, and also prevented the ballast from being fouled due to the upward migration of fines from layers of subballast and subgrade [10,11,12,13]. The results of large scale direct shear tests clearly illustrated the improved performance of ballast due to the use of geogrid with appropriate specifications [14,15]. A field trial was conducted on a section of instrumented railway track in the town of Bulli, New South Wales (NSW), Australia to study the effectiveness of a geocomposite (a combination of bi-axial geogrid and nonwoven polypropylene geotextile) installed at the ballast-subballast interface. The relative performance of moderately graded recycled ballast compared to the very uniform fresh ballast traditionally used, was also evaluated.

2. BALLAST FOULING MEASUREMENTS

Fouling material is defined as the fraction passing the 9.5 mm sieve [16], and in practice, several fouling indices are used to measure fouling. The fouling index (FI) is defined as a summation of the percentage (by weight) of fouled ballast passing the 4.75 mm (No. 4) sieve and 0.075 mm sieve (No. 200) sieve [16]:

\[
FI = P_{0.075} + P_{4.75}
\]

They also proposed the percentage of fouling (% fouling) as a ratio of the dry weight of fouled material passing through a 9.5 mm sieve to the dry weight of total fouled ballast sample. The North American Railway systems use typical ballast sizes ranging from 4.76 mm to 51 mm and Australian Railways [17,18] uses ballast varying in size from 13.2 mm to 63 mm. In view of this, the Fouling Index is defined as a summation of percentage (by weight) passing the 13.2 mm sieve and 0.075 mm sieve to suit the Australian Rail Track conditions [19]:

\[
FI_D = P_{0.075} + P_{13.2}
\]

The results of a sieve analysis of samples of fouled ballast indicated a significant variation in D10 in contrast to that in D90 due to the intrusion of fines. Therefore, a further modification to the Fouling Index was proposed [19]:

\[
FI_D = \frac{D_{90}}{D_{10}}
\]

An assessment of fouled ballast for Queensland Railways was carried out using the D-bar (D) parameter [20]. It is defined as the geometrical mean particle size and is usually obtained from the sieve analysis of a sample of fouled ballast. However, all the above mass based indices gave a false measurement of fouling when the fouling material (e.g. coal) had a low specific gravity. Therefore, the Percentage Void Contamination (PVC) was defined as the ratio of the bulk volume of fouling material to the volume of voids in clean ballast [6]:

\[
PVC = \frac{V_1 \times 100}{V_2}
\]

where \( V_1 \) is the volume of voids in the ballast and \( V_2 \) is the total volume of re-compacted fouling material passing through a 9.5 mm sieve. They recommended cleaning the ballast once the PVC reached 30%. However, PVC does not consider the effect of the void ratio, gradation, and specific gravity of the fouling material, so to incorporate these effects, a new Void Contaminant Index (VCI) parameter is proposed [21]:

\[
VCI = \frac{(1 + e_f - e_b) \times G_{sb} \times M_{f}}{G_{sf} \times M_b} \times 100
\]

where \( e_b \) is the void ratio of clean ballast, \( e_f \) is the void ratio of fouling material, \( G_{ab} \) is the specific gravity of the ballast material, \( G_{af} \) is the specific gravity of the fouling material, \( M_b \) is the dry mass of clean ballast, and \( M_f \) is the dry mass of the fouling material. In general, ballast specifications in Australia and around the world demand a uniform gradation (uniformity coefficient, \( C_u = 1.5 - 3.0 \)) to fulfil the requirements for rapid track drainage. Also, the void ratio of clean ballast (\( e_b \)) will not change significantly. However, there is a significant variation in the void ratio (\( e_f \)), specific gravity (\( G_{af} \)), and gradation characteristics of fouling material such as sand, silt, clay, coal and crushed rock fragments, and the VCI can take all these variations into account. In the current paper VCI is used to measure the amount of fouling.

3. LARGE SCALE PERMEABILITY TEST

A series of constant head, hydraulic conductivity tests were used to measure the hydraulic conductivity of fouled ballast associated with different values of VCI. The large scale
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A permeability test chamber which could accommodate specimens 500mm in diameter and 500mm high was used in this study (Figure 1). In order to prevent the fine particles from washing out, a filter membrane was placed on top of the uniformly graded coarse ballast situated at the base of the apparatus to maintain a free draining boundary. The clean ballast was then placed above the filter membrane and was compacted in four equal layers to represent a typical field density (an initial porosity of 0.408 to 0.416). The bulk unit weights of clean ballast, coal, clayey sand and kaoline clay were 15.98, 8.5, 12.5, and 17.8 kN/m$^3$ respectively. The specific gravities of clean ballast ($G_{sb}$) and fouling materials ($G_{sf}$) namely: coal, clayey sand and kaoline clay were 2.75, 1.5, 2.6, and 2.65 respectively.

![Figure 1: Schematic diagram of large scale permeability test apparatus](image1)

Both uniform and non-uniform fouling patterns were simulated in this large scale permeability test. With the non-uniformly distributed fouling, the ballast layer was compacted first and then the fouling material was added from the top and allowed to infiltrate downwards with percolating water. To simulate uniformly distributed fouling, a given volume of kaolin was pre-mixed with the aggregates and then compacted in 5 layers. For 100% VCI, kaolin was placed at the bottom of the test chamber and then the ballast was placed on top of it and compacted using a vibrating plate, until the required height was achieved for each layer and the excess kaolin was inevitably squeezed out the top. The total volume, the weight of the ballast and its gradation, were kept constant for each test to maintain a similar initial porosity within the ballast.

### 3.1 Testing Procedures

To study the effects of fouling, a series of large scale constant head permeability tests [22] on fouled ballast with different percentages of coal, clayey sand, and kaolin were conducted. It was earlier reported that the linear Darcy’s law was still valid for fresh ballast at low hydraulic gradients (around 1) [23]. Therefore, Darcy’s law that incorporated laminar flow was used in this study. The gradation of clean ballast is illustrated in Figure 2, together with the upper and lower bounds of gradation actually recommended in practice [17]. The details of particle size distributions of various fouling materials used in this study are also shown in Figure 2. The fouled specimen was saturated for at least 24 hours before testing. A number of constant head tests were conducted to investigate the effects of different fouling materials. They were conducted under a steady state flow subjected to a 1.5m head of water with an adjustable overhead tank.

![Figure 2: Gradations of clean ballast and fouling materials](image2)

### 3.2 Results and Discussions

Figure 3 shows the variations of hydraulic conductivity of coal-fouled and sand-fouled ballast with VCI where the fouling material was distributed non-uniformly.

![Figure 3: Variation of hydraulic conductivity with Void Contaminant Index for coal-fouled ballast and sand-fouled ballast (data sourced from [7])](image3)
As expected, the overall hydraulic conductivity of fouled ballast always decreased with an increase in VCI. The current test results showed that a 5% increase in the VCI decreased the hydraulic conductivity by a factor of at least 200 and 1500 for ballast contaminated by coal and clayey sand, respectively. However, this reduction in permeability would not significantly affect the minimum drainage capacity needed for acceptable track operations. Beyond a VCI of 75%, any further reduction in hydraulic conductivity became marginal because it approached the hydraulic conductivity of the fouling material itself. Similar observations were made earlier during laboratory measurements of sand-gravel mixtures, where a high percentage of sand in gravel would provide a hydraulic conductivity close to that of the sand itself [24]. Figure 4 shows the variation of hydraulic conductivity for clay-fouled ballast where the fouling material was distributed uniformly. At low values of VCI, the overall hydraulic conductivity of ballast was relatively unaffected, but beyond a VCI of about 90%, the overall permeability of fouled ballast was almost the same as kaolin clay.

4. USE OF GEOGRID FOR STABILISING FOULED BALLASTED TRACK

In the past, very limited studies dealing with the adverse effects of coal fouling on the strength of ballast have been conducted [25,26,27,28]. When ballast is fouled by breakage or infiltration of fine particles, the particle interaction may change considerably as fine particles clog the ballast voids and grid apertures, reducing the interlocking and frictional resistance between the geogrid and ballast. Fine particles adversely affect the strength and stiffness of track structures [15,26] because as fouling increases, the stiffness of the ballast is significantly reduced. When the amount of fouling materials is excessive, fine particles can dominate the ballast behaviour and ultimately make the track unstable. A series of large scale direct shear tests with clean ballast and coal-fouled ballast showed that as the percentage of fouling increased the shear strength of coal-fouled ballast decreased [28]. The shear strength and apparent angle of shearing resistance of clean ballast and coal-fouled ballast was evaluated under various degrees of fouling using the large scale direct shear apparatus [15] described in this section.

4.1 Experimental Set Up and Procedure of the Large Scale Direct Shear Test

The recommended particle size distribution of ballast (mean particle size of $d_{50} = 35$ mm) was adopted. Using a parallel gradation, the maximum size of the ballast tested in the laboratory was less than 40 mm, which was small enough to avoid any boundary effects. Coal fines were used as fouling material. A polypropylene geogrid with 40 x 40 mm$^2$ aperture was used. The direct shear test apparatus consisted of a 300 x 300 mm$^2$ square steel box 195 mm high that was divided horizontally into two equal halves. A schematic diagram of the test set up is shown in Figure 5. The clean ballast aggregates were compacted in the bottom half of the shear box to a dry density of 15 kN/m$^3$ and then a sheet of geogrid was placed on top. The remaining ballast was then compacted in the upper half of the shear box. Coal fines were spread over each compacted layer of ballast in accordance with the desired VCI.

The tests were conducted at four normal stresses of 15, 27, 51, and 75 kPa. The lower section of the shear box was moved at 2.5 mm/min, while the upper section of the box remained stationary. Each specimen was subjected to 37 mm of maximum horizontal displacement.

4.2 Influence of Coal Fines on the Apparent Angle of Shearing Resistance of Ballast Aggregates

The normalised peak shear stress ($\tau_p/\sigma_v$) and apparent angle of shearing resistance ($\phi$) of clean ballast and coal-fouled ballast are plotted for
different values of VCI (Figure 6). It is evident that the increase in shear stress per unit of normal stress was non-linearly proportional to the normal stress and increased slightly when the normal stress increased.

The coal fines steadily reduced the peak shear stress of the coal-fouled ballast specimens due to a reduction in the apparent angle of shearing resistance. This decrease in the shear strength of unreinforced and reinforced coal-fouled ballast is significant when the vci increased up to 70%, beyond which any further reduction in the shear strength becomes marginal. The apparent friction angle of clean ballast varied between 48° and 65°, depending on the applied normal stress.

5. ROLE OF GEOGRID APERTURE SIZE ON THE INTERFACE SHEAR STRENGTH

Several previous studies focused on the laboratory testing of the soil-geogrid interfaces [29, 30,31, 32] and the ballast-geogrid interfaces [31,32, 33]. An earlier study recommended that the ratio between the geogrid aperture and nominal size of the ballast (D₅₀) should be 1.4 [33]. In order to investigate the role played by the size of the geogrid aperture on the strength of the ballast-geogrid interface for different types of geogrids, a series of large scale direct shear tests were conducted.

5.1 Experimental Arrangement and Procedure of the Large Scale Direct Shear Test

Fresh latite basalt with recommended gradations (D₅₀ = 35 mm) and seven geogrids with different aperture sizes (A) were used for this study. Their physical characteristics and technical specifications are listed in Table 1.

Table 1. Physical characteristics and technical specifications of the geogrids [14].

<table>
<thead>
<tr>
<th>Geogrid type</th>
<th>Aperture shape</th>
<th>Aperture size (mm)</th>
<th>Tₚ,ult (kN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biaxial +</td>
<td>Rectangle</td>
<td>44 42</td>
<td>30 30</td>
</tr>
<tr>
<td>Biaxial #</td>
<td>Rectangle</td>
<td>36 24</td>
<td>55 30</td>
</tr>
<tr>
<td>Biaxial *</td>
<td>Square</td>
<td>33 33</td>
<td>40 40</td>
</tr>
<tr>
<td>Biaxial *</td>
<td>Rectangle</td>
<td>70 110</td>
<td>20 14</td>
</tr>
</tbody>
</table>

extruded type; + welded type; # knitted type; MD: Machine direction; CMD: Cross Machine direction; a Ultimate tensile strength (manufacturer supplied values)

Geogrid was placed at the interface of the upper and lower sections of the shear box assembly with the machine direction placed parallel to the direction of shearing. Tests were conducted at normal pressures of 26.3, 38.5, 52.5, and 61.0 kPa, using a shear rate of 2.75 mm/min. All tests were conducted to a maximum shear displacement of 36 mm.
5.2 Role of Geogrid Aperture Size ($A$) on the Interface Shear Strength

The behaviour of the ballast-geogrid interface could be examined on the basis of the interface efficiency factor ($\alpha$) which is defined as the ratio of the shear strength of the interface to the internal shear strength of the soil [34]. Figure 7 shows the variation of $\alpha$ with $A/D_{50}$ ratio. It was observed that $\alpha$ increased with $A/D_{50}$ until it attained a maximum value of 1.16 at $A/D_{50}$ of 1.21, and then it decreased towards unity as $A/D_{50}$ approached 2.5. The value of $\alpha < 1$ indicated that the particles were not interlocked, whereas when $\alpha > 1$ they were, which effectively increased the shear strength. Based on this variation of $\alpha$, the ratio $A/D_{50}$ was then classified into three primary zones, as explained below:

5.2.1 Feeble interlock zone ($0.95 > A/D_{50} > 0$)

In this zone the particle-grid interlock was weaker than the inter-particle interaction achieved without geogrid because the particle-grid interlock was only attributed to smaller particles (<0.95$D_{50}$) compared to the particle-particle interlock with respect to all sizes. An examination after testing showed insignificant particle breakage, which suggests the interface failure originated from a loss of particle-grid interlock during shearing.

5.2.2 Optimum interlock zone ($1.20 > A/D_{50} > 0.95$)

In this zone the interlocking of relatively larger particles occurred, which lead to the values of $\alpha$ exceeding unity. The value of $\alpha$ attained a maximum of 1.16 at an optimum $A/D_{50}$ ratio of about 1.20. An examination after shearing showed there were many broken ballast particles at the interface, suggesting that the failure was caused by the breakage of initially interlocked particles. This was probably attributed to an increased number of natural flaws (e.g. micro-cracks) in the larger particles [35].

5.2.3 Diminishing interlock zone ($A/D_{50} > 1.20$)

In this zone the values of $\alpha$ were greater than unity but the degree of interlocking decreased rapidly leading to a reduction in $\alpha$ with an increasing $A/D_{50}$ ratio. It was observed that $\alpha$ decreased to almost unity when $A/D_{50}$ exceeded 2.50. This implies that the interface responds in a similar manner as unreinforced ballast; as the apertures increase in size in relation to the sizes of the ballast particles.

The minimum and maximum aperture sizes of geogrid required to achieve maximum efficiency was 0.95$D_{50}$ and 2.50$D_{50}$ respectively. For all practical purposes, the optimum size aperture of geogrid can be 1.15-1.3$D_{50}$.

6. USE OF GEOSYNThETICS FOR STABILISING A RECYCLED BALLASTED TRACK

Geosynthetics have been widely and successfully used in new rail tracks and in track rehabilitation schemes for almost three decades. When appropriately designed and installed, geosynthetics are a cost effective alternative to more traditional techniques. The application of geosynthetics for railway construction can be subdivided into (1) separation, (2) reinforcement, (3) filtration, (4) drainage, (5) moisture barrier/waterproofing, and (6) protection. Geocomposites can provide reinforcement to the ballast, as well as simultaneous filtration and separation functions [8]. A combination of reinforcement by the geogrid and the filtration and separation provided by bonded non-woven geotextile will reduce the lateral spreading and fouling of ballast, as well as degradation, especially in wet conditions. Non-woven geotextile also prevents the fines moving up from the subballast and subgrade (subgrade pumping), thereby keeping recycled ballast relatively clean.

In order to investigate deformations of a multi-layer rail track caused by train traffic, and the benefits of using geosynthetics in fresh and recycled ballast, a field trial was carried out on a fully instrumented track in the town of Bulli [36, 37].

6.1 Site Geology and Track Construction

A site investigation comprised of 8 test pits and 8 Cone Penetrometer tests was carried out to investigate the condition of the sub-surface profiles conditions. The subgrade consisted of a stiff over consolidated silt clay that revealed high values of cone resistance ($q_c$) and friction ratio ($R_f$) in the Electrical Friction Cone Penetrometer (EFCP) tests [38]. The bedrock was highly weathered sandstone having a low to medium strength [39].
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The proposed site for the track construction was located between two turnouts at Bulli, on the south coast of NSW. The instrumented section of track was 60 m long, divided into four, 15 m long sections. The layers of load bearing ballast and subballast were 300 mm and 150 mm, respectively. Fresh and recycled ballast without a geocomposite layer were used in two sections, while in the other two sections, fresh and recycled ballast was used with a layer of geocomposite at the ballast-subballast interface.

6.2 Material Specifications

The particle size, gradation, and other index properties of fresh ballast used at the Bulli site were in accordance with the Technical Specification [18], which represents sharp angular coarse aggregates of crushed latite basalt. Recycled ballast was collected from the stockpiles of a recycled plant commissioned by RailCorp at Chullora yard near Sydney.

Table 2. Grain size details of materials [37]

<table>
<thead>
<tr>
<th>Material</th>
<th>$d_{\text{max}}$ mm</th>
<th>$d_{\text{min}}$ mm</th>
<th>$d_{50}$ mm</th>
<th>$C_u$</th>
<th>$C_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh Ballast</td>
<td>75.0</td>
<td>19.0</td>
<td>35.0</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Recycled Ballast</td>
<td>75.0</td>
<td>9.5</td>
<td>38.0</td>
<td>1.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Subballast</td>
<td>19.0</td>
<td>0.05</td>
<td>0.26</td>
<td>5.0</td>
<td>1.2</td>
</tr>
</tbody>
</table>

6.3 Track Instrumentation

The performance of the track under repeated wheel loads was monitored using sophisticated instrumentation. The vertical and horizontal stresses induced in the track bed were measured by pressure cells. Vertical deformations of the track were measured by settlement pegs, and lateral deformations were measured by electronic displacement transducers. The pressure cells and displacement transducers were connected to a computer controlled data acquisition system. The settlement pegs and displacement transducers were installed at the sleeper-ballast and ballast-subballast interfaces, respectively, as shown in Figure 9.

6.4 Track Measurements

Vertical and horizontal deformations were measured in the field, against time. A relationship between million gross tons (MGT) of rail traffic annually and number of cycles (N) was used to determine the number of load cycles [16]:

$$C_m = \frac{10^6}{(A_i \times N_a)}$$

where $C_m$ = number of load cycles/MGT; $A_i$ = axle load in tons; and $N_a$ = number of axles/load cycle.

Considering an annual tonnage of 60 MGT of traffic, and four axles per load cycle, an axle load of 25 tons gives 600,000 load cycles per MGT. Therefore the results were plotted against both the time and number of load cycles, as discussed below.

6.4.1 Vertical deformations

The average vertical deformations of ballast were plotted against the number of load cycles (N) in Figure 10. They were smaller in the recycled ballast than the fresh ballast, because of its moderately graded particle size distribution compared to the very uniform fresh ballast. Recycled ballast often has less breakage because...
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they are less angular, which prevents corner breakage resulting from high contact stresses. The inclusion of a geocomposite decreased the average vertical deformation of recycled ballast over a large number of load cycles. The capacity of the ballast layer to distribute load was improved by the placement of a flexible and resilient layer of geocomposite, and it also substantially reduced track settlement under high cyclic loading.

The lateral deformation of ballast was also associated with increased internal confinement. Geogrid increased the peak shear stress because interlocking between the ballast and geogrid increased the peak shear stress associated with increased internal confinement. The lateral deformation of ballast was also reduced by this interlocking effect. However, the benefits gained from the use of geogrid were reduced in coal-fouled ballast because the coal fines fill the voids between the ballast particles and coat their surfaces, which decreased inter-particle friction and subsequent resistance to interface shearing. It was also observed that the normalised aperture ratio, i.e. A/D50, had a profound influence on the interface efficiency factor (α). The best size geogrid aperture to optimise the interface shear strength was 1.20D50. The minimum and maximum sized apertures required to attain the beneficial effects of geogrids were 0.95D50 and 2.50D50, respectively.

The large scale direct shear tests revealed that geogrid increased the shear strength of ballast while reducing dilation in the granular assembly because interlocking between the ballast and geogrid increased the peak shear stress associated with increased internal confinement. The lateral deformation of ballast was also reduced by this interlocking effect. However, the benefits gained from the use of geogrid were reduced in coal-fouled ballast because the coal fines fill the voids between the ballast particles and coat their surfaces, which decreased inter-particle friction and subsequent resistance to interface shearing. It was also observed that the normalised aperture ratio, i.e. A/D50, had a profound influence on the interface efficiency factor (α). The best size geogrid aperture to optimise the interface shear strength was 1.20D50. The minimum and maximum sized apertures required to attain the beneficial effects of geogrids were 0.95D50 and 2.50D50, respectively.

The field tests carried out on the instrumented track at the town of Bulli near Wollongong, NSW highlighted that recycled ballast performs well under repeated train loads compared to fresh ballast. This was due to the moderately-graded composition of recycled ballast that reduced inter-particle stresses, compared to the highly uniform fresh ballast recommended by the Australian Standards. The results of field monitoring further demonstrated the potential benefits of using a geocomposite and geogrid to mitigate track settlement under high cyclic loading.

CONCLUSIONS

The performance of ballasted rail tracks under various levels of fouling and the benefits associated with the use of geosynthetics, has been discussed through large scale laboratory tests and full scale field trials. In this study the detrimental effects of fouling on shear strength and drainage characteristics were assessed using a new parameter, the Void Contaminant Index (VCI). It was shown that the VCI could accurately capture the fouling of ballast because it could incorporate the effects of void ratios, specific gravities, and gradations of both fouling material and ballast. Initially, even a small increase in the VCI leads to a significant decrease in the hydraulic conductivity of the fouled ballast, but beyond a certain limit of VCI (50% for coal-fouled ballast and 90% for sand-fouled ballast) the hydraulic conductivity converged to that of the fouling materials itself.

The field tests carried out on the instrumented track at the town of Bulli near Wollongong, NSW highlighted that recycled ballast performs well under repeated train loads compared to fresh ballast. This was due to the moderately-graded composition of recycled ballast that reduced inter-particle stresses, compared to the highly uniform fresh ballast recommended by the Australian Standards. The results of field monitoring further demonstrated the potential benefits of using a geocomposite and geogrid to mitigate track settlement under high cyclic loading.
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gecomposite in track, where it reduced the lateral deformations of fresh ballast by about 49% and recycled ballast by 11%. The gecomposite certainly provided the key functions of reinforcement, filtration and separation, which reduced the vertical and lateral deformation.

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