Potential Remediation of Rail Track Foundations in Poorly Drained Clay Sites with Native Vegetation.

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ABSTRACT: One of the major issues concerning rail infrastructure owners is substructure maintenance. Inadequate intervention can lead to poor track geometry. The problem is compounded by the presence of expansive clays in the formation layer and is often exacerbated when poor drainage softens these clays, leading to progressive shear failures. In some cases full track reconstruction is necessary, which is extremely costly. Rail maintenance engineers observed better formation stability on these same clays where stands of trees had been established adjacent to the rail track. Subsequent investigation showed improved engineering subgrade properties in most cases due to relative soil desiccation. Accordingly, Australian Rail Track Corporation (ARTC) have planted several sites on its network with native vegetation.

KEY WORDS: Rail formation, expansive clay, cyclic stiffness, vegetation.

1 INTRODUCTION

When the majority of Australia's railway was laid over 100 years ago, there was an absence of geotechnical advice to highlight the problems that may occur if expansive clay soils were encountered. The majority of Australia's rail infrastructure is now privatised and although the interstate rail network is more efficient than ever before, the corporations that took over have also inherited long-standing substructure problems, which, according to Indraratna *et al* (1998), comprise a major proportion of track maintenance budgets.

In order to sustain acceptable track geometry, the subsoil drainage is of utmost importance (Selig and Waters, 1994), however effective drainage is not always possible. Independent investigations of poor vertical track alignment for ARTC by Phillips (2001) and Cantrell (2002) established that a major cause of track geometry failure was due to progressive shear failure of softened clays. Potter and Cameron (2004) confirmed that the presence of moisture directly beneath the track in poorly drained sites is detrimental to the strength and stiffness of expansive clay subgrades

Rail maintenance engineers observed that where significant stands of vegetation were present in the rail corridor, the track held vertical alignment better than at adjacent sites with no vegetation. A recent study by Cameron (2001) has confirmed that trees can cause soil desiccation in a semi-arid climate to significant depths, in excess of 4 m. In terms of rail foundations, this is an important finding as cyclic loading on a rail track formation can stress the subgrade to a depth of 4 to 5 m (Selig and Waters, 1994). Therefore trees may influence the behaviour of the entire rail foundation.

A detailed investigation followed to validate the hypothesis that vegetation can improve the strength and stiffness of poorly drained clay rail foundation. The feasibility of introducing vegetation on rail corridors as a remediation technique has been explored subsequently through field trials at selected sites.

2 TEST SITES

2.1 Selection and Vegetation

Sites for soil testing were selected from sections of rail corridor where expansive clay soils were known to be causing problems. Soil pedology (Northcote *et al*. 1975) was used to confirm regions thought to contain expansive clay soils. These regions were further investigated to find specific locations in the same soil type where a suitable representation of vegetated and non-vegetated sites occurred within close proximity of each other. A vegetated site is defined as a section of track having an established stand of trees within 15 m of the track, whilst non-vegetated sites are devoid of any significant vegetation within 50 m. Three sites were selected in the western part of the State of Victoria (Miram, Horsham and Wal Wal) along with one site in central Queensland (Emerald). Table 1 summarizes data on vegetation at each site, which includes the tree species present, height, position (facing in the direction of increasing kilometreage, also called the "down" direction) and the proximity to the track.

Table 1: Details of vegetation at vegetated sites

Site	Species (common name)	Approx height of trees (m)	Position (side of track)	Average distance from track (m)
Miram	Blackbox	4	Left only	3
Horsham	Red gum/ Sugar gum	15	Left only	4
Wal Wal	Various types of gums and wattles	10	Both sides	12
Emerald	Brigalow	10	Left only	7

2.1.1 Prevailing Climates

Climates tend to vary greatly across Australia. The three sites in Western Victoria are within 100 km of each other across an area which is classified as semi-arid. The average recorded climate data in Figure 1 show that Western Victoria usually experiences highest rainfalls during the winter months (June to August) when temperatures and evaporation rates are at the lowest levels. Monthly rainfall exceeds pan evaporation in both June and July.

In contrast, Emerald (central Qld) is classified as an arid climate; pan evaporation exceeds rainfall all year round by about 100 mm/month and temperatures are much higher (about an extra 10°C). Maximum rainfall in Emerald occurs in the summer months (December to February) when temperature and evaporation rates are at their highest.

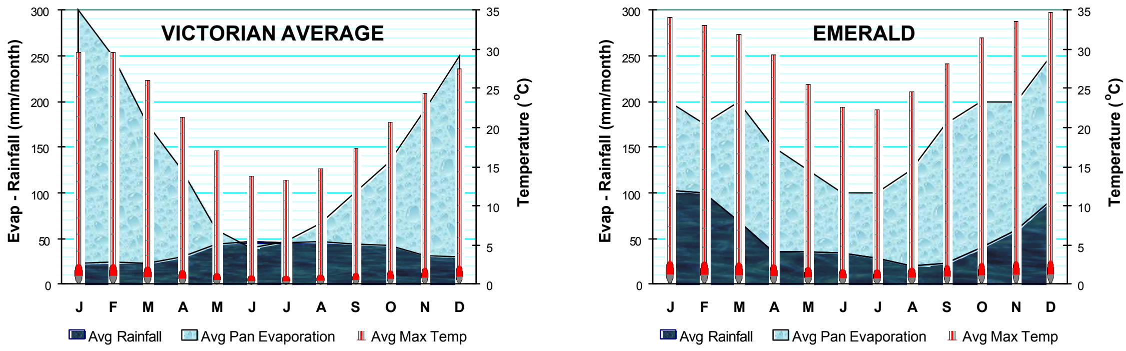

Figure 1: Climate data for soil testing sites (data source Bureau of Meteorology, 2004)

3 METHODOLOGY

To quantify the differences between vegetated and non-vegetated sites, soil samples were taken at each site. Tests were carried out in the laboratory for moisture content, total soil suction, UU triaxial and resilient modulus, in accordance with AS1289 (Standards Australia, 2000), where applicable. In round two, conductivity testing was also carried out on solutions of 1 part dry soil to 5 parts water by mass (Klute, 1986). The resultant conductivity, $EC_{1:5}$, may be converted to solute suction if it is assumed that the salt is sodium chloride. Matric suctions were estimated by deducting the solute suction values from the total suctions.

4 RESULTS AND DISCUSSION

Soil suction, shear strength and resilient modulus data are presented in this section to illustrate the differences firstly between the vegetated (V) and non-vegetated (NV) sites, and secondly, the influence of the two seasonally disparate periods.

4.1 Total Soil Suction

Five continuous soil cores were taken vertically at five positions across the track at each site. Boreholes were advanced 2 m from each ballast shoulder (L2 and R2), at the shoulders (LS and RS) and below the centre of the track (C). Soil samples were taken at intervals of 0.3 m for the first 1 m depth, then every 0.5 m to a total depth of 4.5 m.

Total soil suction is influenced by both salt concentration (solute suction) and the soil's affinity for water in the absence of a salt concentration difference (matric suction). If salinity remains relatively constant at a point, the higher the total suction value, the drier the soil at that point. This assumption is made in the following discussion.

Figures 2 to 5 show the results of soil suction samples taken from round one and two for each of the sites in the form of contour plots. Suction is a pressure, however the logarithm of pressure is usually applied in the form of the historical unit, pF, which is given by the equation:

$$\text{suction in pF} = \log_{10}(\text{suction in kPa}) + 1.01$$

The lighter areas on the contour plots of suction across the track with depth indicate high suction values (4.7 pF or 5 MPa), while the darker shades tend toward the lower limit of measurable total suction by the dew point hygrometer method (3.2 pF or 155 kPa). A minimum value of 3.2 pF was assigned to any readings which indicated lesser values.

The first Victorian site at Miram was classified as red duplex clay (Northcote *et al*, 1975). The soil suction profiles shown in Figure 2 illustrate that the Miram V site had much higher suctions than the NV sites for the entire 4.5 m deep profile. At the NV site, the top 1.5 m was the wettest with suctions of approximately 3.2 to 3.5 pF. After the seasonally dry period in early autumn, moisture was reduced in both the V and NV sites, although most of the variation was experienced in the top metre of the profile. Although Table 1 shows that the trees present at Miram were only 4 m in height, they were relatively close to the track and have had an obvious impact on the entire depth of so il profile investigated.

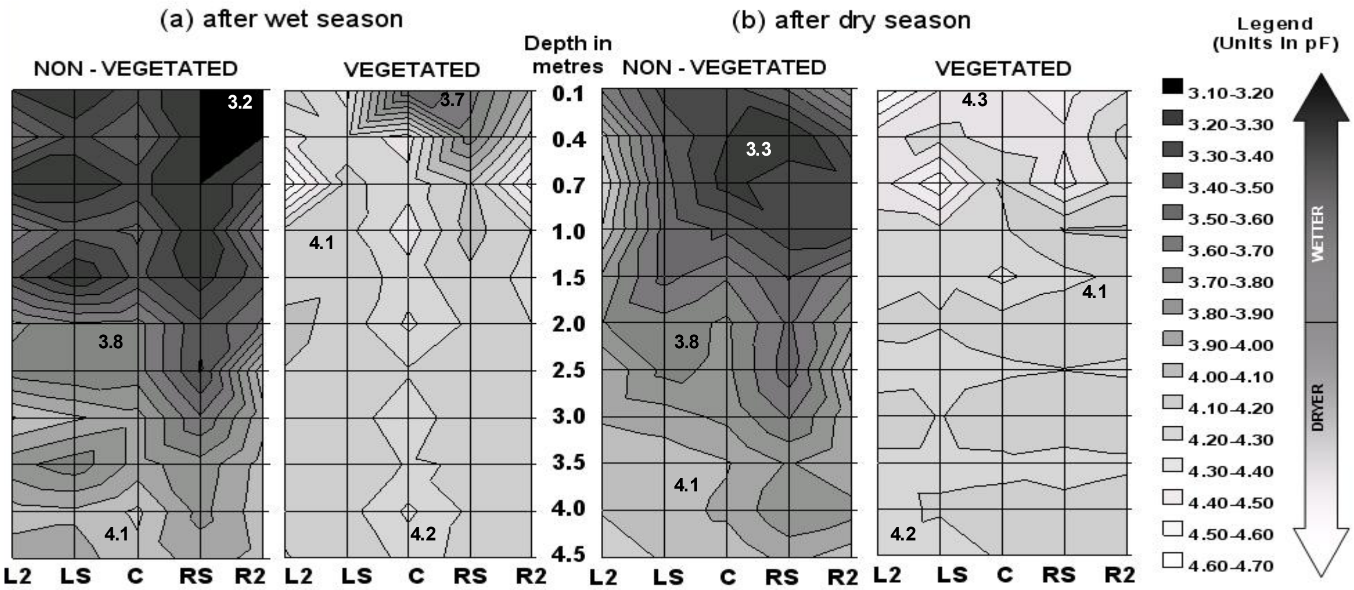

Figure 2: Contour plots of total soil suction at Miram vegetated (V) an d non-vegetated (NV) sites (a) after the wet season and (b) after the dry season

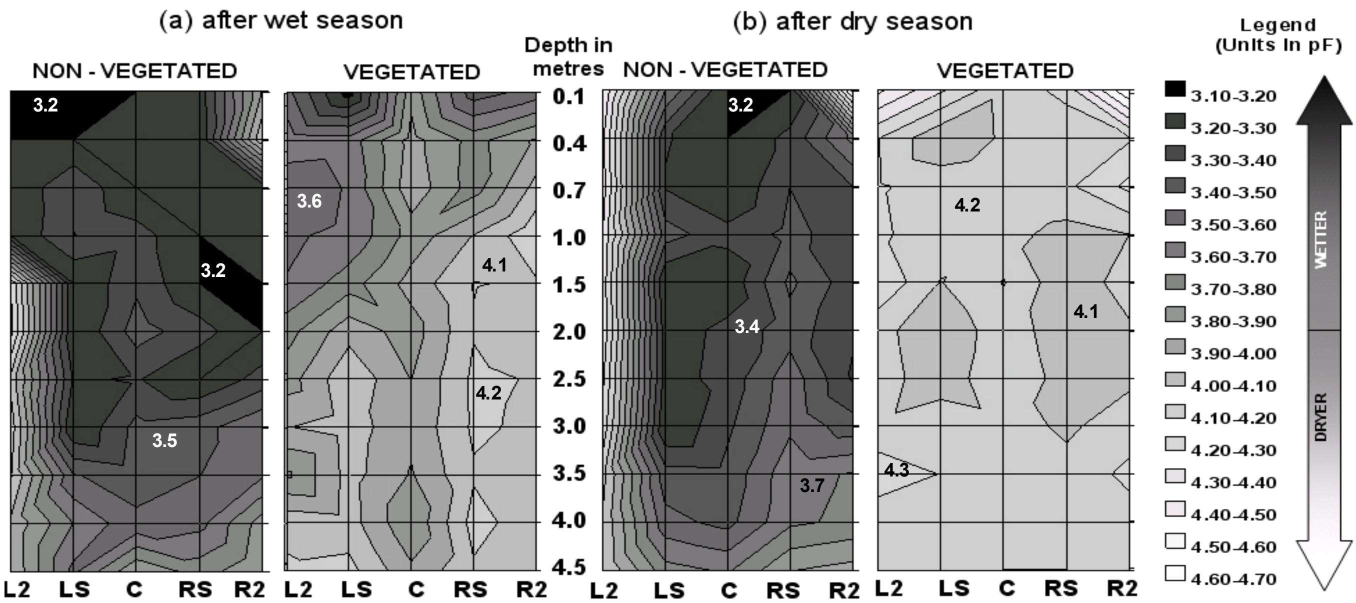

Figure 3: Contour plots of total soil suction at Horsham vegetated (V) and non -vegetated (NV) sites (a) after the wet season and (b) after the dry season

The second site at Horsham consisted of a grey cracking clay soil profile (Northcote *et al*, 1975). Figure 3 indicates a considerable difference in soil suction between the V and NV sites to the full depth investigated. At Horsham the "wetting" penetrated further to a depth of almost 3.5 m in the NV sites. Between the two seasons in which samples were taken, the NV site was little affected, apart from some drying 2 m outside the left shoulder (L2), over a depth of 1.5 m. The dry season appeared to have led to further desiccation of the soil profile in the top 1.5 m of the V site, and quite noticeably near the surface outside the track shoulders. The sugar gum and red gum trees at this site were reputed to be almost100 years old, so it is not surprising that the drying effect is so marked.

Wal Wal, the third Victorian site and furthest from Adelaide, rested on a yellow duplex clay soil profile (Northcote *et al*, 1975). The profile contained numerous sandy lenses throughout the explored depth. The soil at the NV site was found to be practically saturated after the wet season; water flowed freely at the subgrade/ballast interface. Not surprisingly, most of the total suction profile (Figure 4a) was almost uniform at 3.2 pF at this treeless site. The V site at Wal Wal provided the largest difference between V and NV sites of all the sites investigated. Review of the seasonal moisture patterns showed that there is an avenue for limited natural drainage at the left side shoulder (L2) on the NV site; however suctions were still markedly low in the subgrade (3.2 to 3.3 pF), even after the dry season. Seasonal influence on the V site showed similar results to the Miram V site with most of the seasonal desiccation occurring in the top 1.5 m.

Closer examination of Figure 4b shows that a "pocket" of relatively moist soil (3.7 to 4.0 pF) still remained under the centre of track at the V site around the 2 to 3 m depth, possibly due to the vegetation already having sufficient water available from other areas closer to the surface. Tree roots may be expected to use available surface moisture first. Roots will also tend to have a lesser effect on soil moisture at depth the further the tree trunk is away (Richards *et al*, 1983); the trees in this case were 12 m away from the track.

A further point of interest was that the suction profiles at Wal Wal tended to be more symmetrical than at other sites, as vegetation was present on both sides of the track. Accordingly, the foundation would be expected to have relatively uniform shear strength and therefore more uniform bearing capacity.

The final site was a black earth soil profile (Northcote *et al*, 1975), situated in Emerald in central Queensland. Again, Figure 5 shows there is a noticeable difference between the NV and V sites, the predominant variation in soil suction notably occurring after the wet season. Figure 1 showed that the climate is much drier than the Victorian sites and this is exhibited by much higher soil suctions. The scale used in Figure 5 has a minimum value of 3.4 pF (approx 250 kPa) and a maximum of 5 pF (approaching 10 MPa). The climate data in Figure 1 indicated that the highest rainfall occurs usually during the summer rather than the cooler winter months, although evaporation is at seasonally high levels. The rainfall experienced in Emerald during the "wet season" before the soil sampling was recorded at just 230 mm, well below the average of around 400 mm. Consequently the seasonal differences in the suction plots for the NV site were small. The V site seemed to be drier after the wet season. A possible reason for this observation is that although the monthly rainfall is higher, evaporation and transpiration rates are also increased, i.e. trees will have a greater demand and will be able to exert a greater pressure for drawing on soil moisture. Figure 5a shows soil suctions approaching 4.7 to 4.8 pF even down to a depth of 3 m. An upper limit of vegetation-induced soil suction of 4.54 pF (3.1 MPa) is considered to be an applicable upper limit of the wilting point of trees (McKeen, 1992).

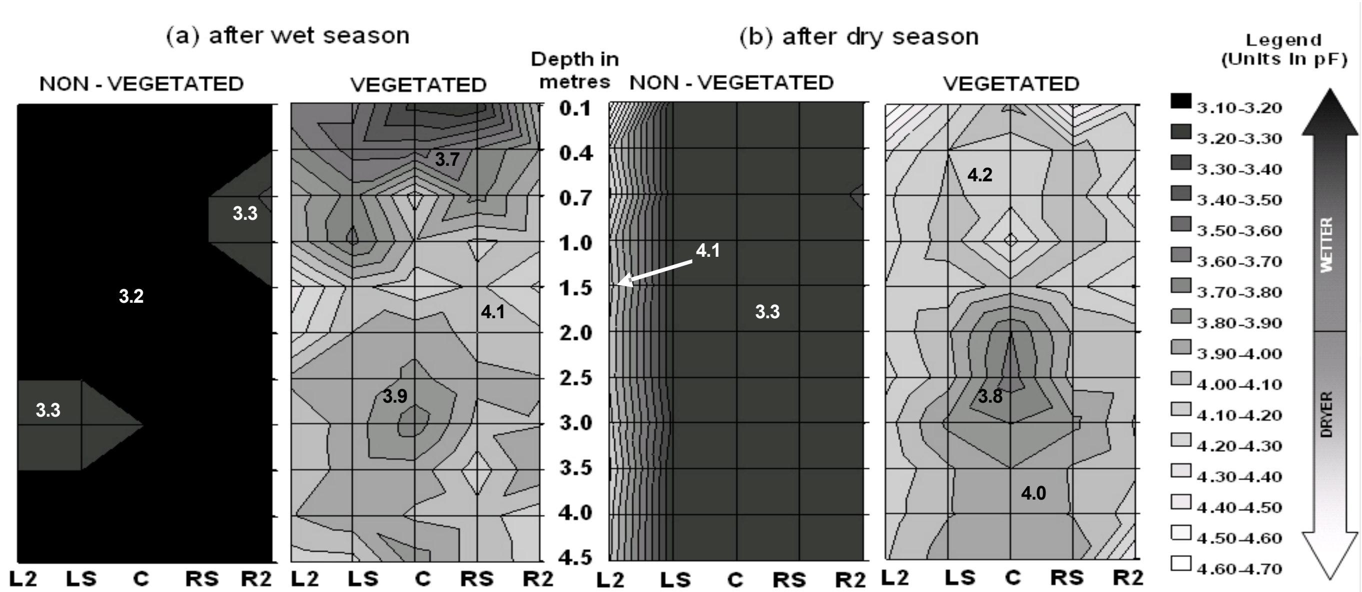

Figure 4: Contour plots of total soil suction at Wal Wal vegetated (V) and non-vegetated (NV) sites (a) after the wet season and (b) after the dry season

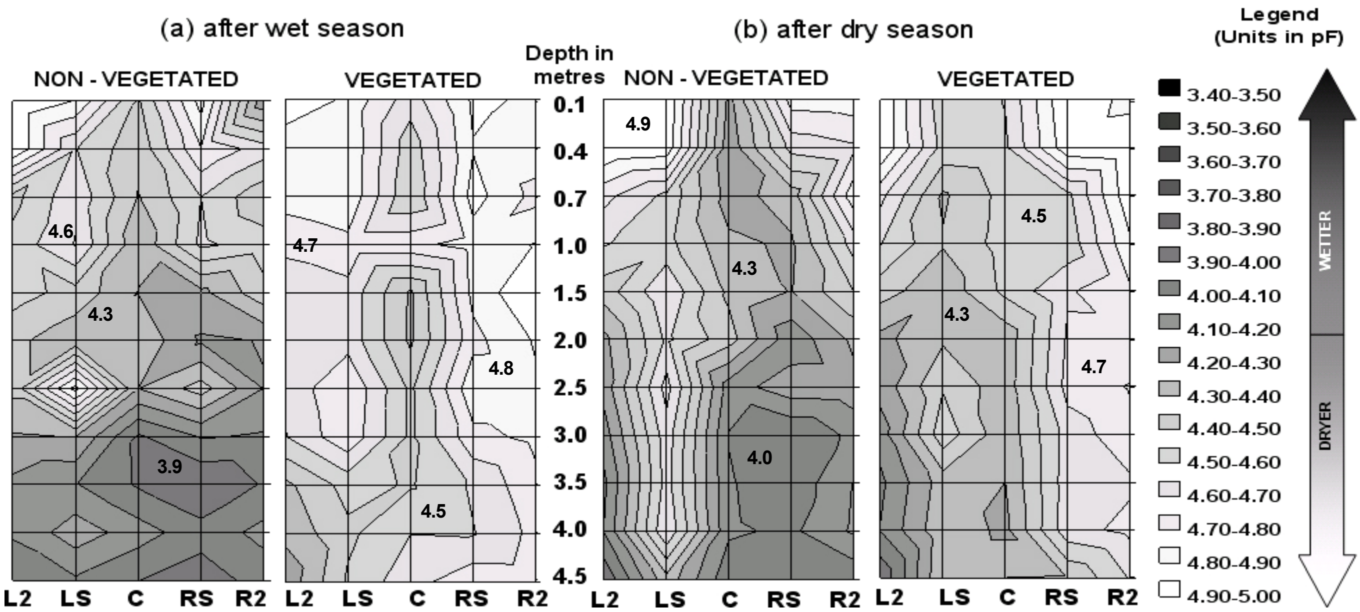

Figure 5: Contour plots of total soil suction at Emerald vegetated (V) and non-vegetated (NV) sites (a) after the wet season and (b) after the dry season

Unlike the Victorian sites, there was evidence of a phreatic surface below the depth of exploration at the Emerald site. A nearby dam on an adjacent property was believed to have influenced the groundwater conditions locally near the NV site, effectively increasing moisture from the bottom of the profile, more so than from the top of the soil by interception of rainfall. The vegetation may have lowered the water table at this site.

4.2 Solute Suction and Matric Suction

Solute suctions were determined from conductivity testing, which was performed only on samples from round two. The solute suction at field moisture content was estimated simply on the basis of the actual moisture content of the soil, compared with the 500% used in conductivity testing. Figure 6 shows the estimated solute suction values, directly under the track (position C) for each of the sites. The greatest difference in solute suction occurred at Wal Wal with the V site having much higher salinity than the NV site for the entire 4.5 m deep profile. Solute suction differences were relatively small for sites Miram and Emerald, but were significant for Horsham. Vegetation usually feeds off soil moisture but leaves salts behind.

The levels of solute suction at the three vegetated sites within Victoria were similar with values below 1 to 1.5 m depth averaging 450, 600 and 700 kPa for Wal Wal, Miram and Horsham, respectively. At Emerald, solute suction increased with depth from 550 to 700 kPa approximately between 1.5 m and 4.5 m.

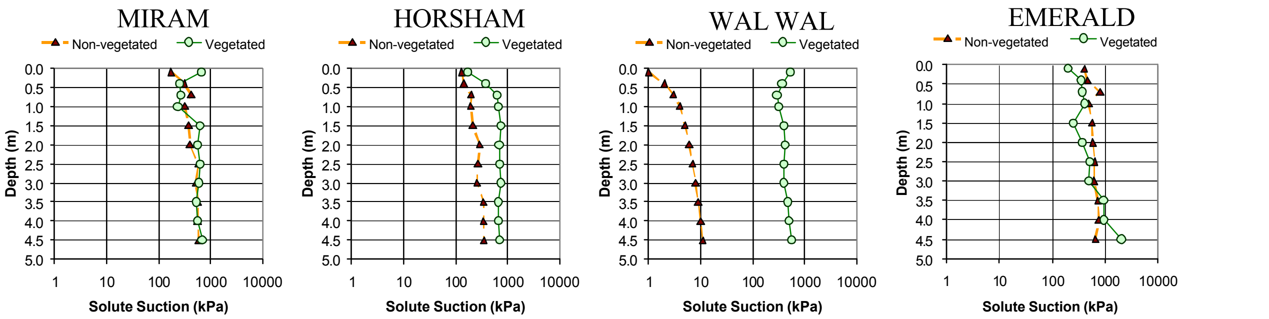

Figure 6: Centre plots of solute suction at each of the sites (round two samples only)

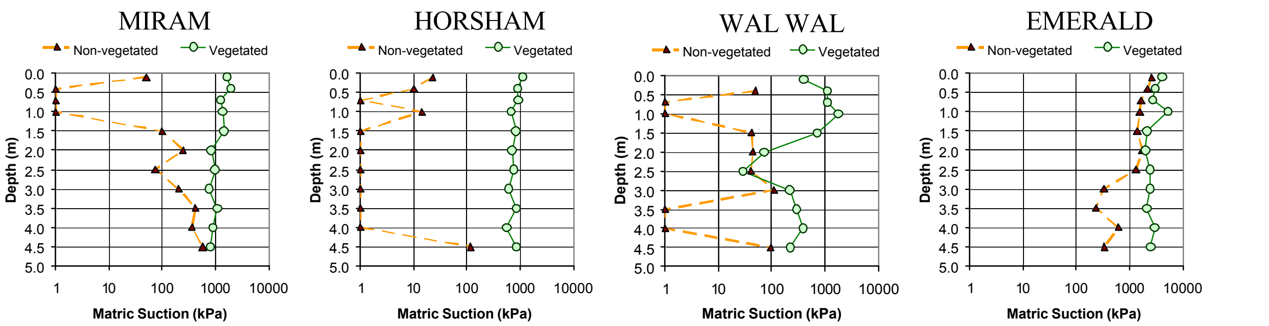

Figure 7: Centre plots of matric suction at each of the sites (round two samples only)

Matric suctions profiles are depicted in Figure7. Matric suctions were not measured directly and so the results shown in Figure 7 rely on the accuracy of conductivity and total suction testing. Wherever negative values of matric suction were predicted, a minimum value of 1 kPa was adopted for plotting purposes. These points most likely indicate saturated soil within the profile.

All of the Victorian plots show that matric suction was significantly higher in the V sites. Matric suction profiles at Miram and Horsham were also quite uniform, averaging 1100kPa and 800 kPa respectively. At Wal Wal the profile shows the soil was saturated at NV site at the 0.7 m and 3.7 m and between the 1.0 and 3.0 m depth and at the V site. The presence of sand lenses amongst the clay may explain this sudden variation, because as soil particle size gets bigger, pore size increases, reducing negative pore pressure or matric suction (Craig, 1997). Emerald matric suction results indicated relatively wetter soil below 2.5 m at the NV site, possibly due to a nearby dam as discussed previously.

4.3 Shear strength

Shear strengths were determined from three stage undrained, unconsolidated triaxial tests. In order to compare shear strengths, a nominal normal stress of 50kPa was adopted. Accordingly the shear strengths are labelled as τ_{50} (refer Figure 8). The results of both rounds of testing are shown in Figure 8. Round one was sampled after the wet season in Victoria and after the dry season in Emerald. For round 2 sampling, seasons were the reverse (after the dry season in Victoria and after the wet season in Emerald). The red X's indicate that the sample either disintegrated upon extruding from the push tube or failed prematurely before a result was obtained.

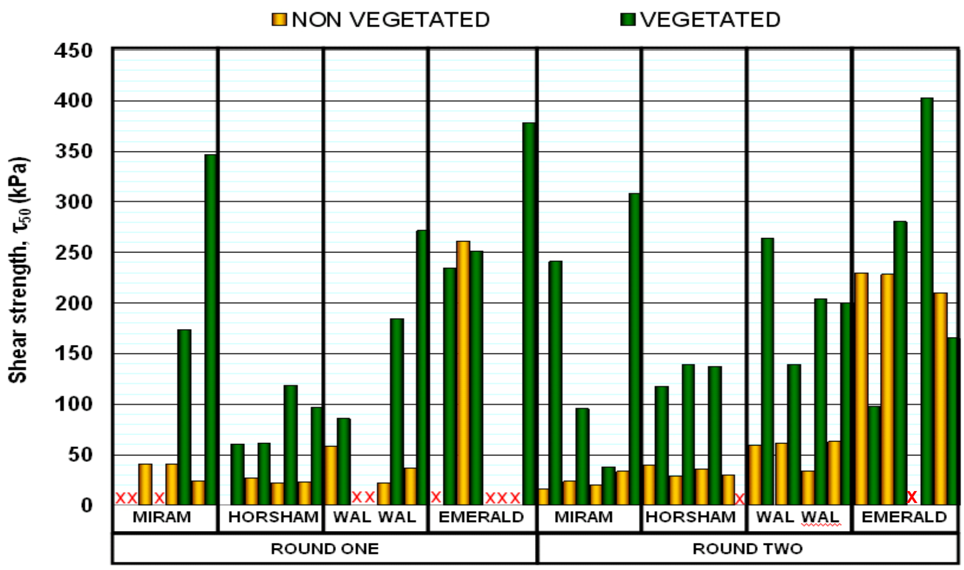

Figure 8: Shear strength, (τ_{50}) comparison for round one and two in vegetated (V) and non-vegetated (NV) sites

It is evident that the samples from the V sites clearly possessed higher shear strengths than the samples from the NV sites, for the three Victorian sites. In Miram, NV values ranged between 30 to 80 kPa whereas V site samples measured between 90 and 347 kPa (up to ten times the comparable strength in some cases). For the Horsham site, the τ_{50} values ranged between 25 to 40 kPa and 60 to 140 kPa for samples from the NV and V sites, respectively. Wal Wal samples showed NV sites τ_{50} values range from 25 to 60 kPa, whilst V samples measured 80 to 265 kPa.

The average level of shear strength was higher at Emerald than at any other site, owing to the higher suctions experienced at this site. However, the Emerald results did not provide evidence of any advantage in shear strength due to vegetation. During testing it was noticed that the soil structure often contained slickensides, pre-empting failure along these planes.

The slickensides were also responsible for the high rate of premature failures during the first round of testing. Extra samples were taken in round two to allow for premature failures.

4.4 Resilient Modulus

Resilient modulus, M_R, is a measure of the cyclic stiffness or the soil's ability to recover elastically under dynamic loading. M_R values are dependent on both confining pressure and deviator stress. For the purpose of comparison of stiffness, the concept of a breakpoint resilient modulus ($M_{R,bp}$) was adopted. The full definition of $M_{R,bp}$ is given in Thompson and Robnett (1979); essentially this value of the modulus pertains to a specific confining pressure and deviator stress. Figure 9 shows the $M_{R,bp}$ values for each of the test sites for round one and round two. As in the previous Figure, the red X's indicate premature failure.

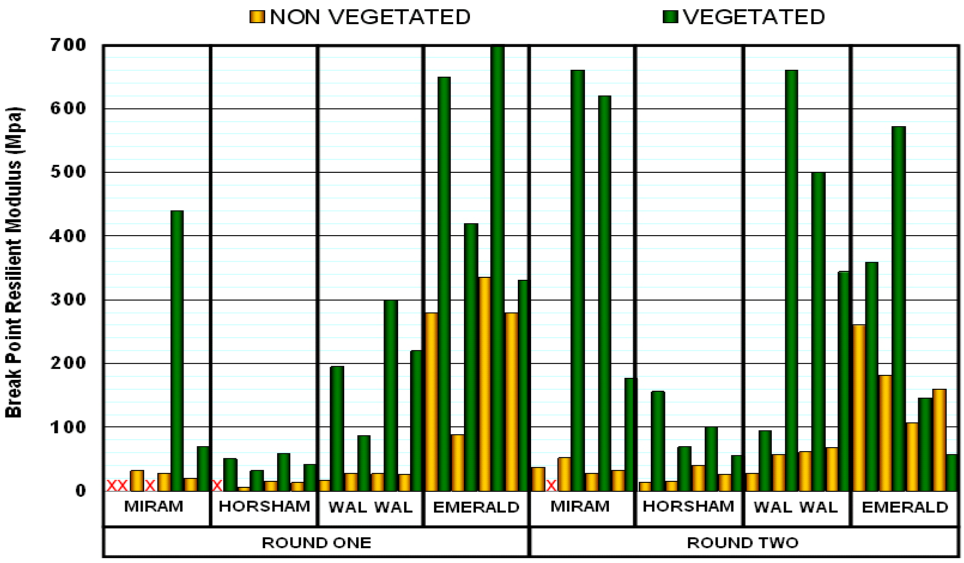

Figure 9: Breakpoint resilient modulus, ($M_{R,bp}$) comparison for round one and two

The breakpoint modulus for the Miram soil varied from 20 to 55 MPa at the NV site compared to 75 to 660 MPa at the V site. Horsham $M_{R,bp}$ values determined on NV samples ranged from 10 to 40 MPa, while V samples were in ranged between 30 and 157 MPa. Wal Wal again showed the best improvement with NV samples having a $M_{R,bp}$ of 20 to 65 MPa and V samples ranging from 85 to 760 MPa. In general, all samples performed better after the dry season (round two in Victoria, round one in Emerald) with the most pronounced difference for Wal Wal soils with an approximate doubling of all moduli. The results from Emerald were intriguing, as Figure 8 showed that shear strengths differed little between NV and V samples, however Figure 9 clearly shows that even minor differences at relatively high levels of soil suction shown (Figure 5) can still have a significant effect on cyclic stiffness.

5 CONCLUSION AND FURTHER WORK

The data presented in this paper has verified that vegetation can improve rail track foundation strength and stiffness at sites where poorly drained clay subgrades exist. Useful engineering correlations will be sought subsequently from the data generated in this project.

It will be many years before trial plantations take full effect, however once the vegetation reaches maturity and reduces soil moisture to a relatively stable level, industry is more likely to accept this approach as an economical and environmentally sustainable solution in dealing with such problem sites.

The next step is to appraise the feasibility of introducing a range of vegetation (grasses, shrubs and trees) in the rail corridor. Methods of site preparation for new plantings are currently under investigation as it has been found that competition with weeds can significantly affect growth. Finally a mathematical model is being developed at the University of Wollongong, with the aim of predicting the influence of trackside vegetation on rail subgrades.

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