Soil Desiccation from Vegetation and its Influence on the Cyclic Stiffness and Strength of Clay Soils

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Abstract: When engineers notice vegetation next to a structure, typically the first thought that comes to mind is usually a negative one. Anecdotal evidence from railway employees suggested the opposite; a noticeable improvement in rail track performance was observed where there were substantial stands of trees adjacent to the track. This perception led to a preliminary study conducted by the author and a colleague. This limited study showed an improvement in soil strength and stiffness at the sides and shoulders of the trackbed in the vicinity of trees on sites with highly plastic clays. The current study investigates trackbed properties, in particular the cyclic stiffness and undrained - unconsolidated (UU) shear strength directly underneath and adjacent to the track. Soil samples were taken from vegetated and non-vegetated sites containing expansive clay soils in western Victoria and Queensland. The vegetated and non-vegetated sites were selected within close proximity of each other to minimize variations in soil properties. This paper reports on the findings of the first half of the project, based on sampling in October on the Victorian sites and in November in Queensland. The results presented in this paper confirm the vegetated sites have improved trackbed strength and stiffness, mainly attributed from an increase in total soil suction (and decrease in soil moisture content).

INTRODUCTION

Vegetation and bioengineering techniques are rapidly developing for improving soil stiffness, slope stabilisation and erosion control. The feasibility of employing these environmentally friendly techniques to enhance the ballasted tracks conditions, particularly in areas with expansive soils, has yet to be investigated.

In Australia, rail corridors have been built on many areas over soft soil formations and upon stiff clays, which are very moisture sensitive (expansive soils which swell and soften on wetting and which harden and shrink as moisture is depleted). On soft soils, poor drainage of the rail formation may cause localised undrained failure of track. On expansive soils, the major problem appears to be the continual softening of subgrades from moisture permeating the ballast and collecting at the ballast-subgrade interface, as it can not readily evaporate in drier seasons. Softened subgrades also lead to accumulation of settlements with cyclic loading.

Although it is well known that trees can significantly reduce soil moisture, there has been a reluctance to adopt vegetation-based stabilisation by geotechnical engineers. One reason is partly due to the unknown performance of vegetation and possibly non-uniform patterns of soil moisture reduction.

The chief goal of the study is to quantify how, where and under which conditions the presence of vegetation leads to an improvement in subgrade cyclic stiffness and strength.

LOCATION OF TEST SITES

Sites were selected from known problem areas reported by track maintenance staff. These areas were narrowed down to where expansive clay soils were evident. A pedological map by Northcote [1] (1975) was also used in the selection process to test on four distinct soil types (given in Appendix A in the site descriptions). The locations of test sites are given in Figures 1 and 2.

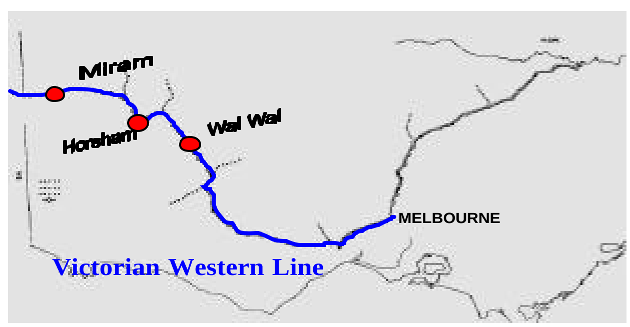

Figure 1 Victorian sites (Miram, Horsham and Wal Wal)

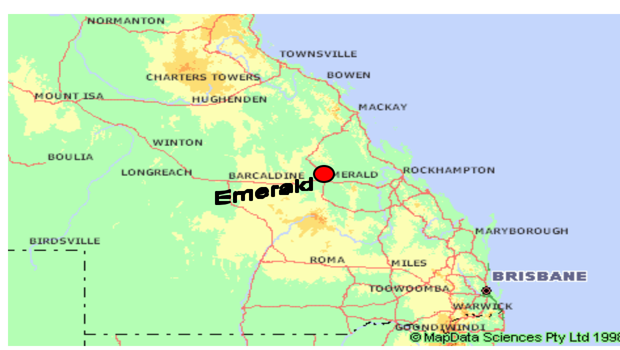

Figure 2 Queensland test site (Emerald)

METHODOLOGY

Thirty continuous cores in total (five at each site) were extended to a depth of at least 4.5 m as illustrated in Figure 1 at the eight test sites (four general locations, sites with and without trees). Atterberg Limits were conducted to assist the classification of soil types using the Unified Soil Classification System.

Total soil suctions were measured in the laboratory with a Dew Point Hygrometer according to AS1289.2.2.2-1992. Moisture content, Atterberg limits and Measurements for soil suction and moisture contents were taken from the continuos cores at 0.1, 0.4, 0.7, 1, 1.5, 2, 2.5, 3, 3.5, 4 and 4.5 m intervals.

Four 50 mm diameter push tube samples were collected to test trackbed subgrade shear strength, using the UU three stage triaxial test, performed according to AS 1289 (Standards Australia [2], 2000). Four 72 mm dameter samples were collected for testing to determine the differences in the cyclic stiffness. Push tubes samples were taken at nominal depths of 0.25 m, 0.5 m, 0.75 m and 1.0 m also shown in Figure 1.

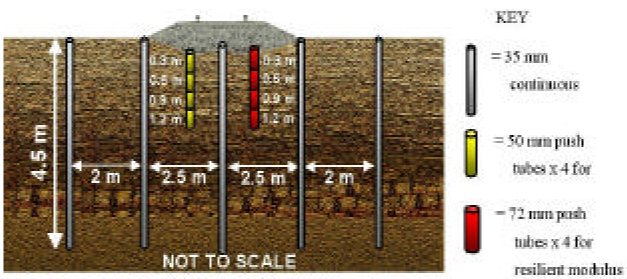

Figure 1 Cross section of sampling

The method used for resilient modulus testing was based on principles from AS 1289, Mundy *et al* [3], (1995) and the American Association of State Highway Officials (AASHTO) [4], 1994. The preparation of samples and procedure for the cyclic loading test used, including values for input parameters are documented in Potter and Londema [5] (2002).

RESULTS

The test results are divided into the following categories: moisture content and total soil suction, static triaxial and cyclic stiffness testing.

Moisture Contents and Total Soil Suctions

Figure 2 shows the comparison of moisture content profiles underneath the track centres of vegetated on non-vegetated sites for all locations.

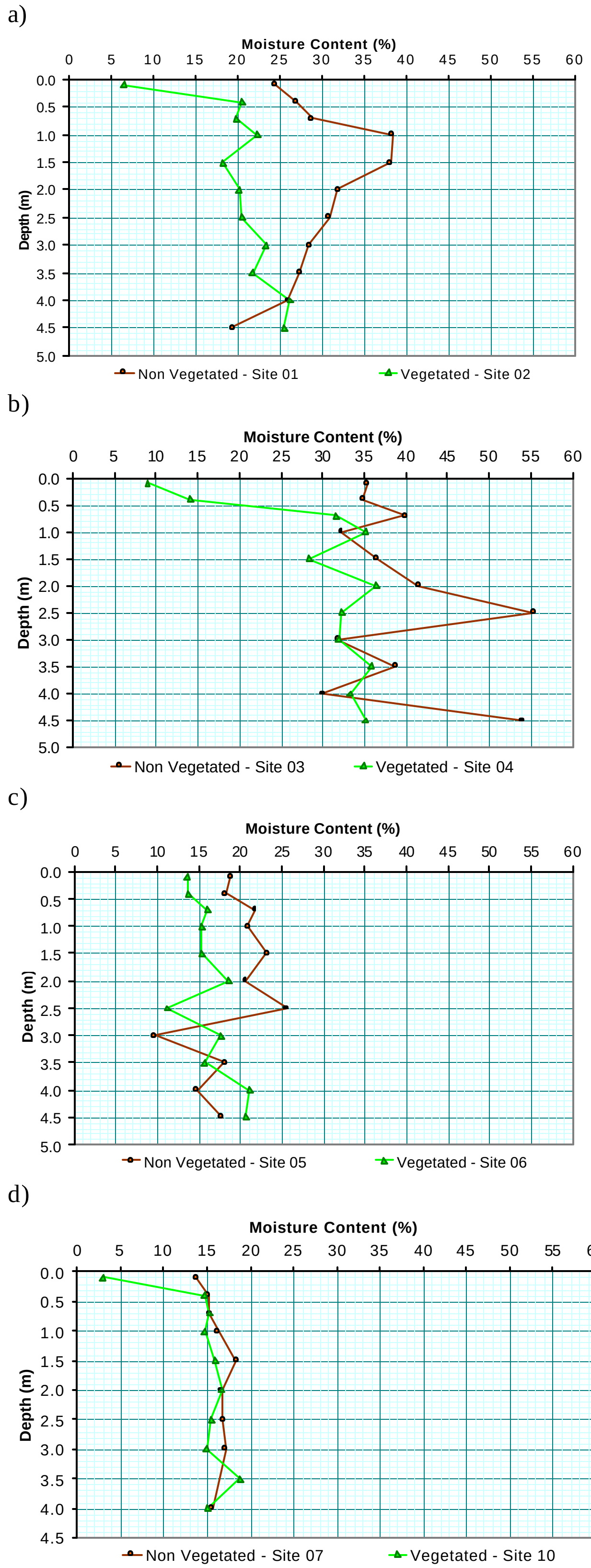

Figure 2 Moisture content profiles under track centres for a) Miram b) Horsham, c) Wal Wal and d) Emerald

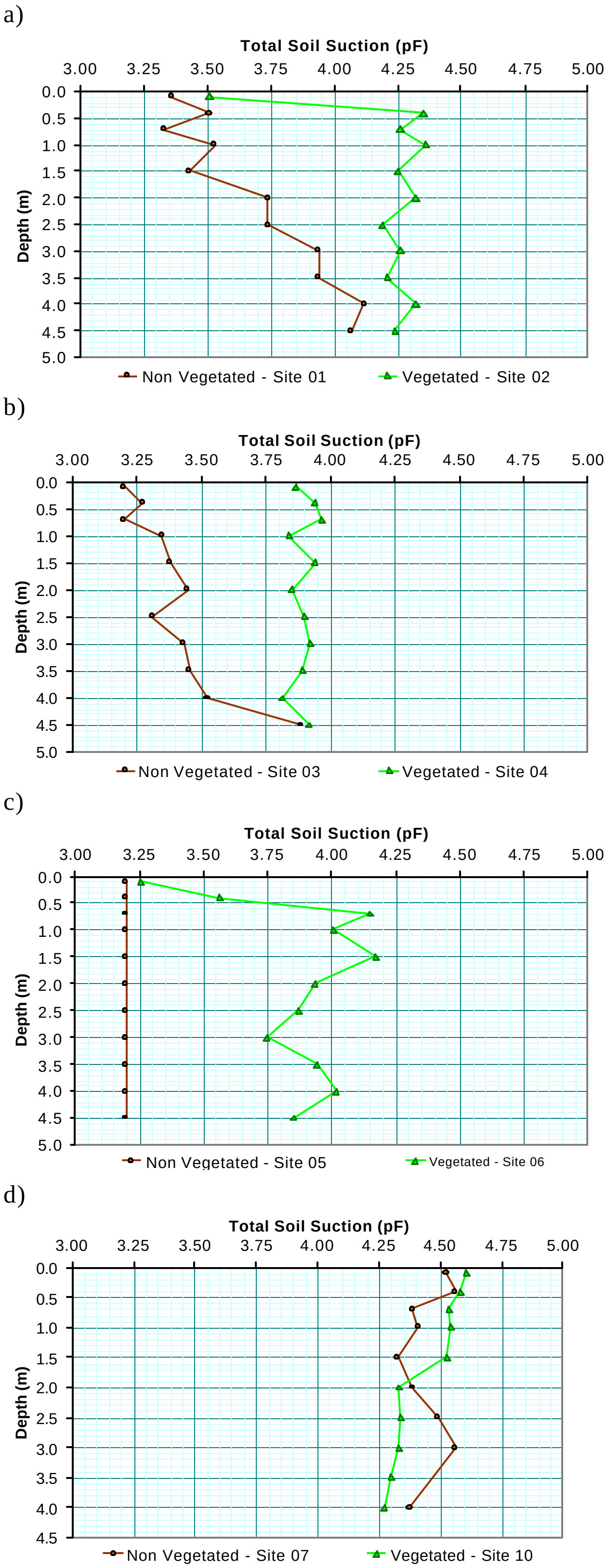

Figure 3 total soil suction profiles under track centres for a) Miram b) Horsham, c) Wal Wal and d) Emerald

Figure 2 illustrated the vegetated sites had a strong trend of drier soil profiles down to a depth of three to four metres at the Victorian sites. Emerald was different, where only the top half metre was drier, then the profile was much the same. Total soil suction measurements revealed a much clearer trend in that the influence of the vegetation was still affecting soil suction level down to a depth of 4.5m. The Wal Wal non-vegetated site 05 indicated that the entire soil profile was near the point of saturation. The Wescor hygrometers have a limit of reading accurately only to a pF of 3.2, therefore any values recorded lower that this were recorded as 3.2pF. Again, Emerald proved to show only a slight increase in soil suction, however this occurred down to a depth of 1.5 to 2 m..

Static Triaxial Testing

The UU three stage triaxial test was used to calculate the shear strength of the top 1 m of subgrade directly below the ballast-subgrade interface. Unfortunately, not all samples were able to give a result due to the sample containing ‘foreign matter’ such as sub-ballast or natural intrusions such as calcium carbonate or tree roots. Other samples also failed early in stage one due to being brittle. Figure 4 shows the results of the successful tests.

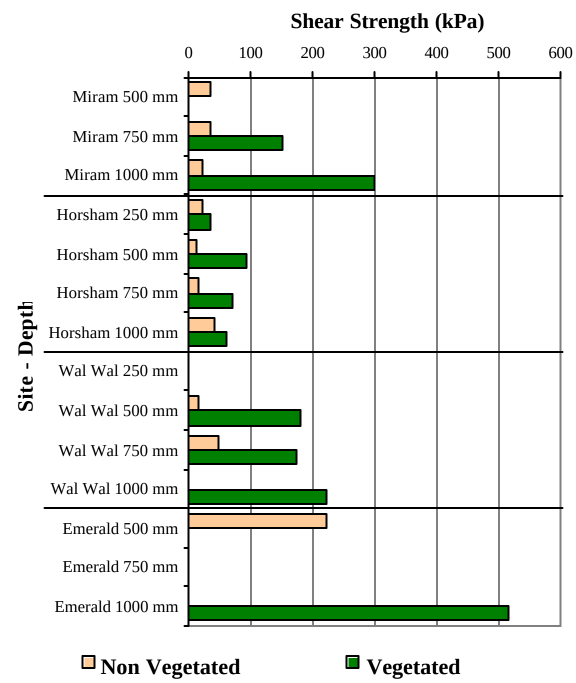

Figure 4 Shear strength (UU) comparison

Although there a quite a few missing results there is a definite relationship that exists. In all cases where a comparison can be made, the vegetated sites have higher shear strengths, with the Miram site at 1 m depth having more than a ten-fold increase (around 30kPa as opposed to 300kPa).

Resilient Modulus Testing

A comparison of resilient modulus is difficult to present concisely as it is not a single value, the range of values are dependent on input parameters such as deviator stress, $\sigma 1$, and confining pressure, σ_3. To overcome this, the author has adopted a modified version of Thompson and Robnett's 'break point modulus', Mr_{bp} (cited in Lee *et al* [6], 1997). The Mr_{bp} value is taken at the intercept where σ_1 = 41.4 kPa on the curve where σ_3 is closest to 20 kPa. An example of how a typical Mr_{BP} value is derived is demonstrated in Figure 5 below.

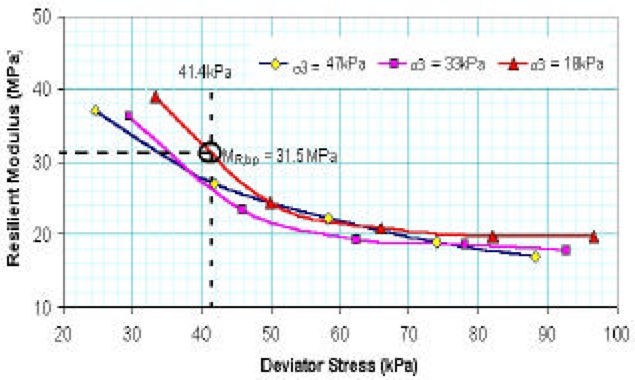

Figure 5 Example of a break point modulus value

The resilient modulus break point values were calculated and are presented in Figure 6 below. At a glance, it is easy to see that the vegetated sites all faired better that the non-vegetated sites.

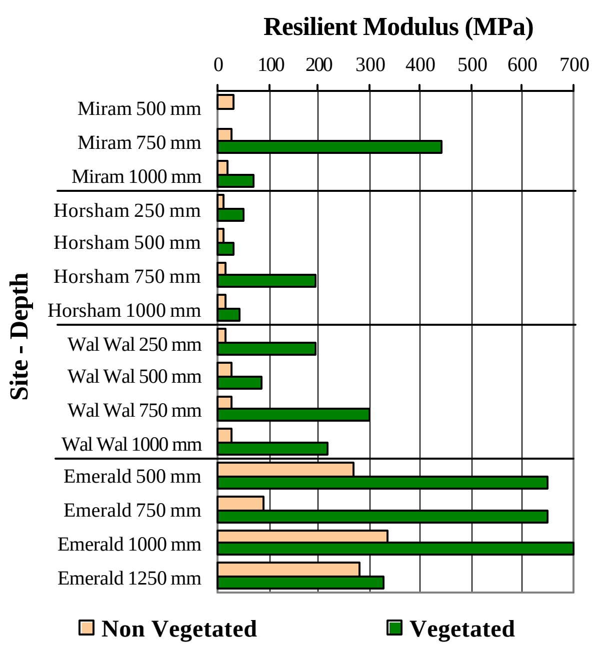

Figure 6 Cyclic stiffness comparison using Mr_{bp} values

Results shown in Figure 6 were not a complete surprise, as it is well known that resilient modulus improves with a higher suction value. It was however, very interesting to see such a dramatic increase (at least double the values down to 1 m) in resilient modulus at the Emerald sites, given that there was not a big difference in moisture content or soil suction.

CONCLUSIONS

The data presented gives a strong case that the presence of vegetation has benefits in improving the strength and cyclic stiffness of clay soils. It is however, only the first step in a series of understanding how to implement strategies using vegetation as a remediation tool. The next stage investigates the same sites again, and will focus on the seasonal variability on soil properties of the vegetated and non-vegetated sites.

ACKNOWLEDGEMENTS

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APPENDIX A GENERAL DESCRIPTION, VEGETATION AND SOIL TYPE OF TEST SITES

SITE DESCRIPTION	VEGETATION PRESENT	SOIL TYPE (Northcote [1] 1975)
Site 01 (Miram Non Veg) About 2km west of the town of Miram – relatively remote	Has no trees within 100m, but sparse ground cover is evident at the shoulder	Red Duplex
Site 02 (Miram Vegetated) 150 m west along the track of site 01	8m tall trees are present on the south side of the track, located approx 5m away from the track shoulder	Red Duplex
Site 03 (Horsham Non Veg) On a section of corridor that runs parallel to the Western Highway	No trees within 2km, however some growth near the track shoulders consisting mainly of 100 to 200mm high weeds	Deep Grey Cracking Clay
Site 04 (Horsham Vegetated) Also on a section of track that runs parallel to the Western Highway. 2 km northwest of site 03	The vegetation is on one side only on the southern side closest to the Western Hwy, consisting of 15m high Red Gums and Sugar Gums, located 3m from the track shoulder.	Deep Grey Cracking Clay
Site 05 (Wal Wal Non Veg) Access to this site can be quite difficult in wetter months. Located in a remote section of corridor	A few remnant small shrubs near the boundary, however unlikely to be influential as the root system is assumed to have no influence beyond 2m given their small size	Yellow duplex clay with sandy lenses in the first 4m of the soil profile.
Site 06 (Wal Wal Vegetated) 50 m south along the track from site 05	Clusters of 10-12m tall trees exist on both sides of the track approx 10m away from the track shoulders.	Yellow duplex clay. Sandy lenses as above.
Site 07 (Emerald Non Veg) This site should be just clear of the hydrostatic influence zone of the dam located around the 7.5 km. Cotton fields are adjacent to both sides.	Graded about 2 years ago, this site contained 2-3m high shrubs. Presently it contains no vegetation within 3m of shoulder .A few small saplings exist about 7m away.	Black Earth
Site 10 (Emerald Vegetated) Located approximately 450 m west of site 07	A mature stand of 12-15m tall trees is present on the southern side only. The trees are approximately 7m away from the toe of the ballast.	Black Earth