Lime Slurry Pressure Injection of railway subgrades

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ABSTRACT

Lime Slurry Pressure Injection (LSPI) is used in railway track maintenance operations as a ground improvement method to control geotechnical properties of problematic subgrades such as strength, stiffness and shrink/swell behaviour. In this practice, probes are forced to depths within the formation where pressure injection of chemically active slurry takes place. Slurry seams entrained by this process throughout the soil profile subsequently react with soil mineral components to imbue the subgrade with competent engineering properties.

The specific advantage of LSPI is that it requires minimal line disruption as the process can be completed around track schedules and it has been shown empirically to be an effective method for improving the performance of railtrack infrastructure. Limitations of this method include the relative degree of uncertainty regarding the physical distribution of slurry within the soil profile for soil-stabiliser reaction, and recognizing how this may translate to a favourable response in the operation of railtrack infrastructure.

A review of the historical development of this technology and its performance has been offered along with a case study of in-field stabilisation. By analysing macro- and micro-scale properties of LSPI stabilised soils a series of tentative guidelines have been offered for the effective application of what is regarded a convenient and cost-effective railtrack stabilisation alternative.

1 INTRODUCTION

Lime Slurry Pressure Injection (LSPI) is a stabilisation operation that has been utilised by the railway industry to improve the geotechnical performance of problematic railtrack subgrades and embankments that persistently fail to meet serviceability requirements. In this practice a hirail mounted rig is driven to a project site, the probes forced through the ballast to target depths in problematic subgrade soils and cementitious slurry of lime and fly ash is injected under hydraulic pressure. Pumping proceeds at typical pressures of 800-1,000kPa in a series of up-staged 1m intervals and ceases when slurry is observed to breakout at the surface or when a maximum pressure is reached. This slurry penetrates fissures and void spaces, opening planes of hydraulic fracture to form complex interconnecting networks of slurry within the soil profile. This situation is illustrated in Figure 1.

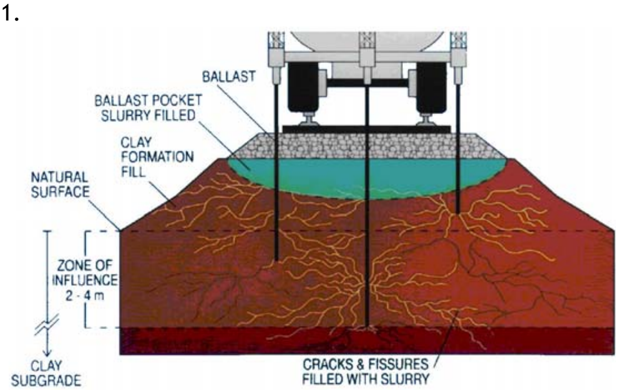

Figure 1: Pressure Injection of railtrack subgrades (Thiele and Adamson 2005)

The geotechnical properties of problematic soils may be improved with the subsequent reaction of soil and slurry components to affect a favourable shrink/swell, compressibility and shear strength response of the underlying formations (Ingles and Neil, 1971; Joshi et al. 1981). The distinct advantages of this technology include its relative economy when compared to other ground improvement options such as deep mixing, lime piles or replacement/reconstruction (Griffin 1997). It requires minimal track closure time as the process is completed within a matter of hours and rail schedules can be reinstated immediately after injection.

Although this technology has been used internationally for over half a century its understanding is largely interpretive with field experience and empirical relationships forming design standards. The literature that is available is scattered in diverse and obscure publications and is sometimes contradictory. Depending on the equipment used, design slurry admixtures and injection protocol, this process has seen a confusing assortment of names that reflect the proprietary nature of its development (ie Drill-inject, L/FASPI, STABIL-PAD, Lense Grouting, Hydrofracture Grouting). While technically imprecise for situations including cementitious slurry admixtures, for the majority of cases the most common moniker remains LSPI.

This document offers a review of the available literature that describes technical processes behind this technique and a trial site at Breeza, New South Wales is used as a case study to explore these concepts. It offers advice for the effective application of LSPI to problematic soils.

2 BACKGROUND

The pressure injection of a low viscosity particulate grout directly into soil environments at depth is a practice that has found application to a variety of projects of ranging geotechnical requirements. Early experiences of cement and sand slurry injection of railtrack subgrades have been recounted by Smith and Peck (1955) using both hydraulic and pneumatic pressure that displaces water pockets and fills voids to ultimately strengthen and stiffen infrastructure without disrupting rail operations. Ingles and Neil (1971) reported on the successful use of grout injection to control the differential surface movement to seasonal changes in moisture content and stress/strain properties in a series of field trials in a variety of soil profiles using lime as well as cement slurries. They found that cement was less successful for this purpose. Likewise, Petry et al. (1982) assessed the use of lime and fly ash to control shrink/swell properties in a large scale field trial for preconditioning high plasticity clays that were to support an airport runway in the Dallas-Fort Worth area. A review of the reduced plasticity and concomitant improvement in the swell properties of heavy clays in the context of railtrack subgrades and embankments has been presented in papers by Joshi et al. (1981), Rogers and Bruce (1991) and Griffin (1997). Rao and Rajasekaran (1994) apply lime injection to stabilise submerged deposits of soft marine clay in what is considered to be an example of a particularly adverse geochemical environment for soil-stabiliser reaction.

An attempt at formalising laboratory methods to assess the suitability of field soils based on the gain in shear strength has been offered by Borden and Baez (1991). In these tests samples of compacted soils are glazed with lime and flyash slurry for direct shear strength determination. This is seen as recognition that the aim of seams is to imbue a strength response within the subgrade.

These papers present experience garnered across a range of soil types and project requirements from Australia, the US, Europe and India. In subgrade soils they identify high-plasticity clays as the principle soils to benefit from this treatment and demonstrate the control of volumetric instability to changes in moisture content through laboratory and in field studies. Lime solution affects a change in the fundamental physico-chemical properties of natural soils and offers limited improvement to strength properties (Ingels and Neil, 1971). In railway embankments cement slurries are being employed in cases where strength and compressibility are to be improved by filling voids, displacing entrapped water and by reinforcing slip planes in cases of progressive slope failure (Smith and Peck 1955).

The equipment used to deliver slurry to soil profiles varies from a simple manual drill-inject operation to modified tractors or hirail trucks mounted with multiple probes that are pushed directly into soils. Slurry components also range from a simple lime solution to include additives that improve the flow properties and agents that affect the strength properties of the set product.

Rheological aids such as surfactants, asphalt emulsions or bentonite can enhance the flow and stability characteristics of slurries (Chandler 1997). Cement or supplementary pozzolans such as fly ash have been used to improve the nature of cementitious reaction while polypropylene fibres may add improved tensile strength and durability to a brittle reaction-product.

3 TECHNICAL CONCEPTS

The achievable standard of geotechnical improvement at the project site will reflect the interaction of soil and slurry components in geomechanical processes of injection as well as subsequent physico-chemical and cementitious processes (Wilkinson, 2004). The principal aim is to disperse high volumes of cementitious slurry within the subgrade by infiltrating fissures inherent in the soil fabric or through propagating planes of hydraulic fracture with slurry following the path of least resistance during injection. Mitchell (1981) commented that the key to a beneficial geotechnical response is through the encapsulation and isolation of soil chunks (peds). The displacement of accumulated water in pockets by a denser grout and the sealing of flow paths to surface infiltration may be a specific aim of ground improvement with the intrusion of voids such as tension cracks or shrinkage cracks. The subsequent cementitious set of slurry components and the stiffening of soils within intimate contact of slurry seams may serve to reinforce the load sustaining macroscale properties of the soil (Chandler 1997). This complex network of seams may additionally act as hydraulic barriers to restrict the seasonal moisture content flux.

The principal mechanism of improvement in high-plasticity soils in semi-arid and temperate climates is the control of shrink/swell behaviour. A boost in the electrolyte concentration at colloid surfaces with the hydrodynamic dispersion and diffusion of calcium cations alters the fundamental water absorptive properties of the soil and causes the flocculation and agglomeration of clay particles (Ingles and Neil, 1971). The overall affect is a material of increased load sustaining and decreased shrink/swell properties on an intrinsic microstructural scale (Joshi et al. 1981).

These concepts have been explored in the following field trial.

4 CASE STUDY

A site alongside railtrack infrastructure near the town of Breeza in NSW was injected with a lime and fly ash slurry in a simulation of the LSPI operation. The site was returned to for electrical friction Cone Penetrometer Tests (CPT) and U-tube samples while a trench was excavated to expose the soil profile. The purpose of this investigation was to trace the volumetric distribution of slurry deposits within the soil horizons, to explore evidence of the geomechanical response with the soil fabric and to test the physico-chemical interaction of soil-stabiliser components in laboratory studies of retrieved samples.

Local soil types at the site consist of tertiary residual trachytes overlayed with quaternary alluvial deposits derived from basalts. The soil conditions at this site have been associated with gilgai formations in a generally flat lying terrain of poor drainage (Banks 1994). The uppermost 2 metres has a high clay fraction of notable smectite clay mineralogy that contributes to an identified shrink/swell hazard. The upper meter is stained with humus, carbonates and littered with organic debris. At depth there is low-plasticity silt with high proportions of plagioclase feldspar. Kaolinite and quartz are ubiquitous throughout the profile. The area has been cleared of trees and only a sparse cover of grass remains at the surface.

Figure 2 shows a typical CPT sounding with three distinct soil types: a very stiff upper horizon, a firm clay at approximately 2-3m and silt at depths below 3m. These soils have adequate strength properties such that failure of railtrack infrastructure to meet serviceability criteria is regarded as being caused by shrink/swell behaviour. CPT results can be used to detect the presence of entrained slurry, as indicated on Figure 2. Slurry seams are detected as localised peaks in tip resistance at 0.8, 1.2, 1.6 and 2.4m depth. There are difficulties in qualifying these features in silts and sands owing to the similar tip response on the CPT sounding. The retrieved U-tube samples were also used to test the geotechnical response and to observe the interaction of soil strata and slurry components in laboratory studies (Wilkinson 2007).

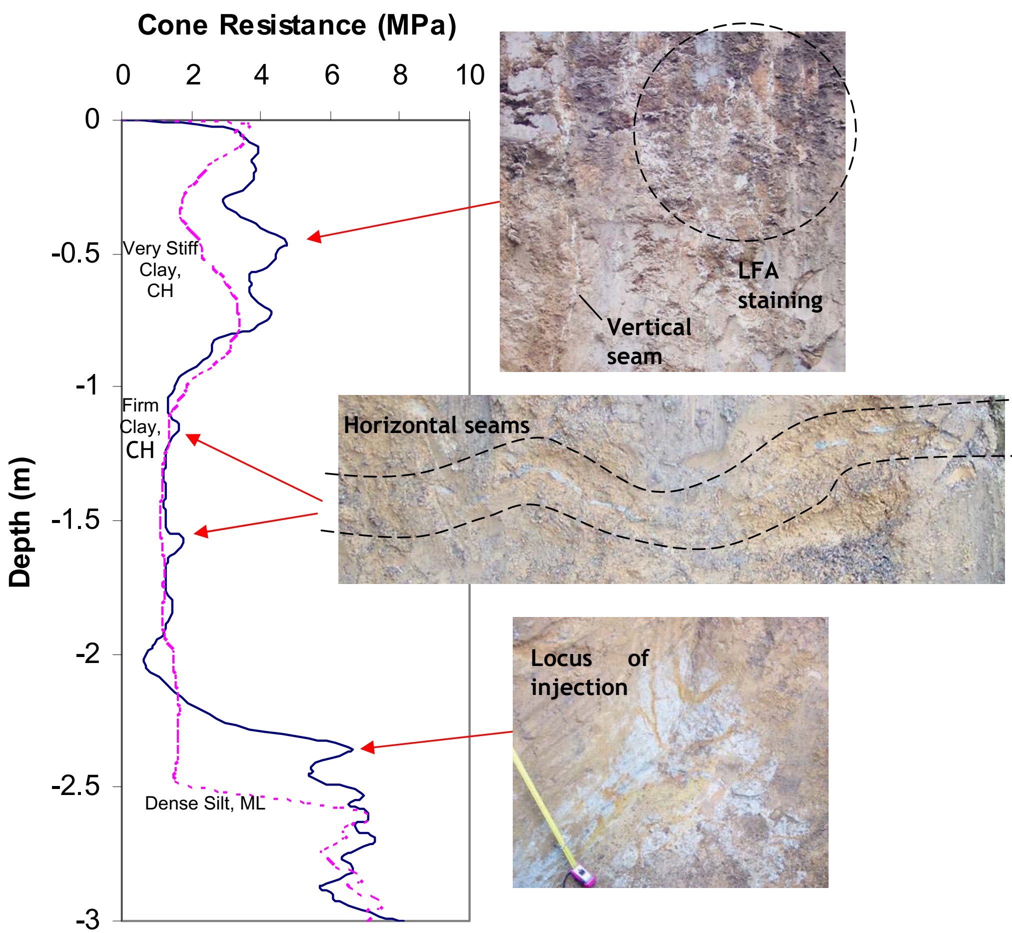

Figure 2: CPT trace of unstabilised soil profile (hatched line) and stabilised pad (solid line) with identified lime-flyash features

One-dimensional CPT sampling methods restrict detection to seams of horizontal and sub-horizontal alignment. They demonstrate a distinct gain in strength with increased resistance at seams to tip penetration. A review of the exposed profile indicates that there is a tendency for seams to approach verticality and spill out at the surface by the course of root channels and shrinkage cracks. The tortuous upward trend of slurry seams in the upper horizon is depicted in Figure 2, with white deposits of lime/flyash liberally staining the vertical shrinkage cracks. Discrete 2-dimensional planes of hydraulic fracture are typical of the slurry seams at lower levels in the horizon. Stress crossover effects of simultaneously operating probes assist the nucleation and propagation of horizontal planes of hydraulic fracture at depth within the soil profile (Jafari et al. 2001).

These slurry seams undergo a series of physico-chemical and cementitious reactions within the soil profile to improve the engineering performance of the greater soil mass. The nature of these reactions is shown in Figure 3, a Scanning Electron Microscope image of the slurry interface with soil. To the left of the image clay minerals have agglomerated with the outward diffusion of calcium from the slurry plane. Toward the centre of the image these soil aggregates are immersed in an amorphous alkali alumino-silicate gel. At greater magnification the gel was observed to feed off clay and fly ash mineral components and immerse both, extending from the right of the image throughout the slurry seam. This provides the seam with intimate chemical and physical bonds to native soil components. The seam comprises of packets calcite and similar crystallite forms in what resembles a primitive cement paste.

Fly ash activated with lime is regarded a more durable material than brittle cement owing to a delayed and metastable state of reaction that gives it ability to recover strength after the disruption of bonds, a process termed "autogenous healing". This is an important trait when considering the significant dynamic and repetitive loads being applied to the railtrack infrastructure without allowance for curing. This may also account for the varied reported results of cement slurries in LSPI stabilization.

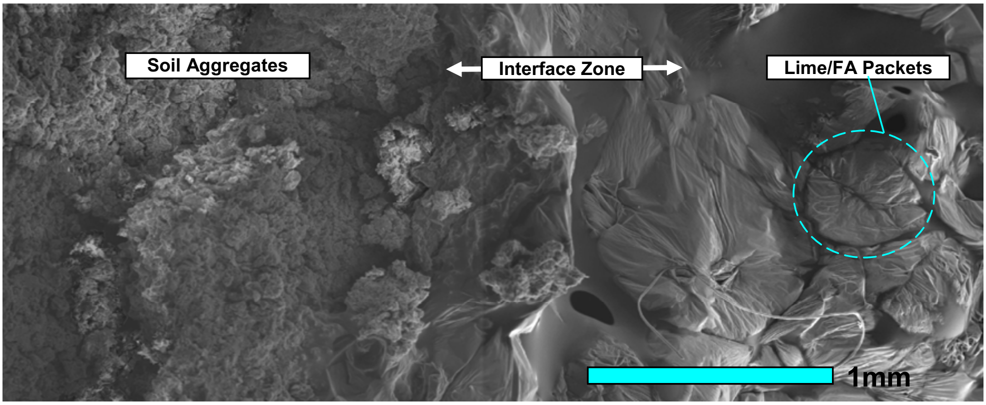

Figure 3: SEM image of soil and stabiliser physico-chemical interaction

The benefits of these identified phenomena include reduced shrink/swell potential by the flocculation of clay colloids as calcium ions diffuse into the surrounding soils, confirming the explanation of Ingles and Neil (1971). There is an additional strengthening of the soils that is evidenced by the increased tip resistance on CPT traces supporting the assertion that extensive networks of entrained slurry seams act as structural elements to reinforce the subgrade, as explained by Chandler (1997). The occupancy of macro-pores by slurry also acts to obstruct the flow channels to surface water infiltration that may otherwise cause swell through the depth of the profile (Wilkinson et al., 2007).

5 CONCLUSIONS

LSPI is a stabilisation operation that improves the intrinsic physico-chemical properties of soils and reinforces the load bearing properties of subgrade soils. The published literature suggests the result is a decreased shrink/swell response to seasonal changes in moisture content and improved strength and deformation properties. Furthermore, the flow channels that convey moisture to lower strata of the soil profile are physically obstructed with slurry by the injection process. The standard of improvement depends on the exposure of soil material to stabiliser components and the subsequent reaction. As such, bulk porosity may be a suitable indicator of slurry uptake by soils. In high-plasticity soils the most suitable time to conduct injection is when the subgrades are at their driest such that the flow channels of shrinkage cracks are at their most accommodating and matric suction at its highest.

The published literature offers a variety of geotechnical and geoenvironmental situations for which the process is being employed. Depending on the application, design slurries have included a variety of stabilising agents and admixtures. Lime slurries alter the swell properties of clay minerals while cement is seen to fill voidspaces and reinforce the strength properties of native soils. It has been demonstrated that lime and fly ash slurries may serve both these roles with the additional benefits of chemical and physical resiliency.

Ultimately, it is important to use engineering judgement to assess sites that are suitable for LSPI stabilisation based on an understanding of the serviceability requirements of railtrack infrastructure and what may realistically be achieved by this process as weighted against the merits of other railtrack reconditioning options. The distinct advantages of this option are that minimal track closure time is required and its relative economy.

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