RETHINK OF THE DESIGN PHILOSOPHY OF LIME STABILISATION

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ABSTRACT

Lime Stabilisation of subgrades in Queensland fell from favour following some instances of poor performance in the late 1970's. In 1996, a Steering Committee comprising representatives from industry, lime manufacturers, and Queensland Main Roads began to review literature and conduct research into lime stabilisation, especially developing long-term strength of the subgrade.

Traditional methods of the design of lime stabilised subgrades initially involved adding sufficient lime to improve the plastic properties, and more recently sufficient to achieve a target pH.

In 1997 members of the steering committee reviewed a design procedure based on research work by Little (USA) who recommends that the percentage of lime to be incorporated in the subgrade should be based on the peak 28day UCS achieved at different percentages of lime. Little believes that design based on the previous pH method may not always be conservative

Little explains that at the higher lime concentrations he recommends, the pH is raised sufficiently high to allow the silicon and the aluminum in the clay to be dissolved, and these can then form stable compounds in a pozzolanic reaction similar to that which occurs with Portland cement. Based on long term US data that the resultant strength gains are permanent and ongoing.

Queensland Main Roads has now constructed two projects with lime stabilised subgrades near Warwick in South East Queensland. These were based on extensive laboratory testing. The performance of these pavements is being monitored and the results to date are exceeding expectations. Results to date also suggest that designers should be able to take account of the increased strength provided by a lime stabilised subgrade layer in pavement designs.

INTRODUCTION

Lime stabilisation of pavement materials is not a new innovation. Various forms of lime stabilisation have been used for thousands of years and until the invention of Portland cement in the 19th Century, lime was widely used for building construction. Early Roman roads utilised lime as a stabilisation agent.

Lime stabilised subgrades were used for in excess of 20 years in Ipswich City Council with excellent results. In Ipswich, lime stabilised subgrades were used as a substitute for pavement materials, as there were no naturally occurring suitable pavement materials within the old Ipswich City Council boundaries.

Queensland Main Roads also extensively trialled lime until the late 70's when it fell from favour. Currently, within Queensland Main Roads, if subgrades are stabilised with lime, no recognition of any improvement to subgrade strength is permitted in the design of the overlying pavement.

If the lime is to be used as a moisture control binder for clayey soils and for its strength as a pavement layer, a design model and laboratory test method is required to soundly base the quantity of lime required to achieved optimum strength and performance.

This paper examines use of a variety of methods to establish the lime content for clay soils with high PI. Field trials were undertaken and the results are listed in this paper. Some Interim recommendations are provided based on this design and construction experience.

UNDERSTANDING THE PROCESS

Lime stabilisation may be defined as soil modification or soil stabilisation (Little, 1995). Researchers now believe that with the addition of low amounts of lime, the calcium present causes an initial ionic exchange, which results in flocculation (or edge to face reorientation of the clay plate-like particles). This flocculation has a dramatic effect on the soil, in terms of a reduction in PI, improved workability and shear strength. However, these strength gains may only be temporary, and can be easily reversed if the soil is exposed to moisture. Soil modification using low levels of lime can often be a most economical construction expedient, as it allows one to drive heavy construction machinery and place and compact pavement layers over subgrades through which one had difficulty in walking on the previous day!

Alternatively, Little notes that with the presence of sufficient lime, it is possible with many soils to achieve pozzolanic reactions. The pozzolanic reaction is illustrated by the following equations:

$Ca^{++} + OH^{-}$ + Soluble Clay Silicon → Calcium Silicate Hydrate (CSH)
$Ca^{++} + OH^{-}$ + Soluble Clay Aluminium → Calcium Aluminate Hydrate (CAH)

Clay-silica and clay-alumina become soluble or available only in a high pH environment. Little notes that for lime stabilisation to be successful to attain significant strength gain, sufficient lime must be made available to provide for the initial soil modification, to maintain a high pH environment to liberate the soluble Silicon and Aluminium, and to provide free Calcium to form the pozzolanic reactions.

Various methods have been used to determine the appropriate application rate of lime. For Plasticity Index (PI) reduction and workability improvement (i.e. soil modification), sufficient lime should be added so that additional quantities do not result in a change in the Plasticity Index. This is known as the "Lime Fixation" percentage. For soil stabilisation, Little recommends that the Thompson design method should be used. This method involves the use of pH testing (the Eades and Grim Procedure, see Appendix A for summary of test procedure) to determine whether a soil is "reactive" to lime and to estimate an approximate lime content, (known as the "Lime Demand") augmented by 28 day UCS testing to establish the optimum lime content. The optimum lime design occurs when the plot of UCS versus lime peaks. An additional 0.5 to 1% lime could be added to allow for variation in mixing and pavement materials.

APPLICATION OF THEORY INTO PRACTICE

Review

In 1996 Queensland Department of Main Roads setup a steering committee consisting of Main Roads staff and industry representation. The committee reviewed various existing lime stabilisation projects (Evans, 1997) and oversaw lime stabilisation trial projects on two new construction jobs in the black clays near Warwick, Queensland.

Killarney Road Trial

The laboratory testing for this project consisted of a lime percentage based on lime fixation and lime demand. For the lime fixation design method the amount of lime is based on the need to overcome the plasticity of the soil to be stabilised, that is for the PI to reach a stable value. Figure 1 shows the laboratory results for the impact of various quantities lime on Liquid Limit, Plastic Limit and Plasticity Index. The data indicates that 3 to 4% of hydrated lime was sufficient for PI stability, and this compares well with past design experience in Queensland.

In addition, pH tests were taken to establish the "lime demand" defined as the lowest percentage of lime required to achieve a pH of 12.4. This more recent design approach is known as the Eades and Grim method, and the pH data is plotted in Figure 2. Although interpretation of this data is subjective, it was estimated from this Figure that about 6% lime would be required to ensure sufficient lime to allow a pozzolanic reaction to take place.

During construction of this project, a range of lime contents was used in an attempt to verify the "lime demand" design approach. Quicklime was used at concentrations of 3%, 4%, 5% and 6% by mass of soil. These values may be equated back to hydrated lime using a factor of 1.3. In addition, a control section with no lime was mixed with the stabiliser.

After the first year of construction the following conclusion could be drawn;

- There is a marked difference in appearance and insitu CBR between the sections stabilised with 3% quicklime and 6% quicklime. When attempts were made to force a sharpened steel cylinder through the material stabilised with 6% quicklime, to obtain a core sample, no penetration was possible due to the high bearing strengths. The area stabilised with 6% quicklime appeared to be "monolithic", whereas sections stabilised with lesser concentrations were not as well bound.
- Insitu CBR results (after approximately 6 months) obtained by back-analysis of deflection data using the CIRCDEF program are reproduced in Figure 3
- Lime stabilisation provided significant constructability benefits for this job. Despite 50 mm of rain falling over a weekend on this black soil flood plain country, work was able to proceed the following Monday, and one could drive over the most recently stabilised section without penetration. The project proceeded without delays.
- The use of quicklime proceeded smoothly, without the normal dust problems previously encountered with the use of hydrated lime. Considerable steam was generated during the slaking process.

It is proposed to continue to perform deflection testing of this pavement, to monitor its long-term performance. Assessments will continue to be made of the modulus to assess whether this improves over time. At the time of preparing the paper the road was still in pristine condition (see Figure 4). However, it could be expected that over time, the short control section comprising a thickness of only 200 mm of granular pavement over high plasticity black soil in a flood plain should exhibit pavement distress. Roughness testing may be appropriate in the years ahead to further quantify the performance of the various lime contents.

Freestone Creek to Eight Mile Intersection

The second project to be constructed involved the widening of a section of the Cunningham Highway that extends east for 4 km from its intersection with the New England Highway, and commenced approximately 13 km from Warwick. Most of the Cunningham Highway in the section between Warwick and Cunningham's Gap is constructed over soils of very high plasticity. Previous attempts to construct conventional pavements through this section have resulted in relative short service lives, due to a combination of excessive moisture changes in the underlying subgrades, and poor quality pavement materials. Based on research work undertaken by Main Roads Transport Technology Division at Cooroy bypass on the Bruce Highway north of Brisbane, one solution considered for the Freestone project was to provide a total pavement depth of approximately 900 mm, that is to provide a bridging layer over this expansive subgrade. This was not feasible in this widening job, as the existing embankment height is generally of the order of 300 mm or less, so it was decided to lime-stabilise the subgrade, to provide the lower 300 mm of this pavement. A full depth structural asphalt overlay was constructed under a separate contract.

Following a similar approach to that adopted in the Killarney Road trial, laboratory testing was carried out to determine the lime fixation and the lime demand Figures 5 and 6 show the laboratory test results. In addition, following the recommendations by Little, 28-day UCS tests were carried out for various lime contents as shown in Figure 7. This laboratory test method is sometimes referred to as the "Thompson Method"

From a comparison of Figures 5 to 7, it is readily apparent that design based on either the traditional "Lime Fixation" method, or the more recent Eades and Grim (Lime Demand) method yields considerably less lime than the currently recommended Thompson method (approximately 3% and 6% hydrated lime respectively to the test method).

For the Thompson method, the peak 28 day UCS result occurs with 9% Hydrated Lime. Applying a conversion factor of 0.757, this equates to 6.8% quicklime. Allowing an additional 1% for variations, the design adopted was 8% quicklime.

In contrast to the Killarney road trial, which carries relatively low traffic, this trial was on the National Highway that is the major freight route between Brisbane and Sydney. It is not normally considered appropriate to conduct trials incorporating different amounts of lime on a road of such strategic importance and therefore, a conservative approach was taken and 8% quicklime adopted throughout. However, an unstabilised section was also installed at the end of the job, to allow comparisons to be made.. The laboratory soaked CBR results for this material (see Figure 8) demonstrate the dramatic improvements which laboratory testing indicated could be achieved by the addition of lime to this material.

Ongoing monitoring is underway to assess the long-term strength achieved from the stabilisation of this job. Results to date are most promising.

Deflectometer tests were conducted using the 40kN Heavy Weight Deflectometer, approximately 6 weeks following job completion, and these were back analysed to determine the Modulus. The results of this analysis are shown in Figure 9.

UCS Cylinders were taken during the stabilisation process, and tested during the initial 6 months following completion (see Figure 10).

Results of this testing would indicate that the initial strength gains are permanent and ongoing.

CONCLUSIONS

Further insitu testing will be carried out on these projects and subsequent trial work on lime stabilisation will continue in the Warwick district under the direction of the Steering Committee.

Based on current research and experiences in Border district (QLD), the following interim recommendations would appear to be appropriate given the current state of knowledge:

1. Where long-term strength gain is required in the subgrade thorough laboratory testing should be undertaken. The quantity of lime required to adequately stabilise subgrades for strength cannot be based on a "rule of thumb".
2. Adequate quantities of lime should be used. At this stage, it would appear that a conservative approach would be to base the design lime content on Thompson's method, and adopt a lime content which yields the maximum 28 day UCS. Less conservative approaches have an element of risk, which is probably not warranted given the moderate marginal cost of adding the additional lime.
3. Until firm data is available from controlled trials using appropriate lime contents for particular soil types, it may be prudent to continue to assume that lime stabilised subgrades do not contribute greatly to pavement strengths. It is acknowledged that this recommendation could appear to be ultra-conservative. However, once adequate data becomes available from trials, design methods should change to allow exploitation of this technology.
4. Long term data based on lime stabilisation using high doses of lime should be developed in co-ordinated controlled trials. These trials should also collect data on soil classifications so as to gain maximum value.

REFERENCES

Evans, P (1997) *Update on Lime Stabilisation* QMR Technology Transfer Seminar, Brisbane.

Little, D, N (1995) *Handbook for Stabilization of Pavement Subgrades and Base Courses with Lime* Kendall Hunt Publishing Company, Iowa, USA.

APPENDIX A

The following appendix is a summary of the procedure presented in the appendix to ASTM C-977 and commonly referred to as the Eades and Grim test. The steps in the test are:

1. Representative samples of air-dried, minus No. 40 soil to equal 20 grams of oven-dried soil are weighed to the nearest 0.1 gram and poured into 150 ml (or larger) plastic bottles with screw tops.
2. Because most soils require between 2 and 5 percent lime, it is advisable to set tip five bottles with lime percentages of 2, 3, 4, 5 and 6. This will ensure, in most cases, that the percentage of lime required can be determined in 1 hour. Weigh the lime to the nearest 0.01 gram and add it to the soil. Shake to mix the dry soil and lime.
3. Add 100 ml of CO_2-free distilled water to the bottles.
4. Shake the lime-soil and water until there is no evidence of dry material on the bottom. Shake for a minimum of 30 seconds.
5. Shake the bottle for 30 seconds every 10 minutes.
6. After 1 hour transfer part of the slurry to a plastic beaker and measure the pH. The pH meter must be equipped with a Hyalk electrode and standardised with a buffer solution with a pH of 12.00.
7. Record the pH for each of the soil-lime mixtures. If the pH readings go to 12.40, the lowest percentage of lime that gives a pH of 12.40 is the percentage required to stabilise the soil. If the pH does not go beyond 12.30 and 2% lime gives the same reading, the lowest percentage that gives a pH of 12.30 is that required to stabilise the soil. If the highest pH is

12.30 and only 1% lime gives a pH of 12.30, additional test bottles should be started with larger percentages of lime.

The major limitations of the pH test is that it does not establish whether the soil will react with lime to produce a substantial strength increase, and the strength data is not generated for use in evaluating mixture quality.

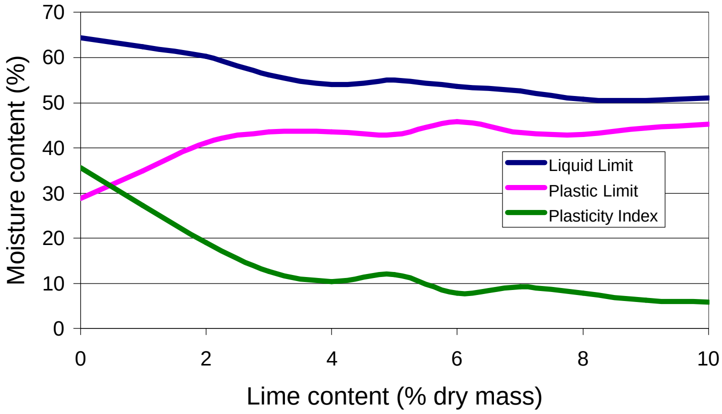

Figure 1 Lime content versus liquid limit, plastic limit and plasticity index for Killarney road trial pavement.

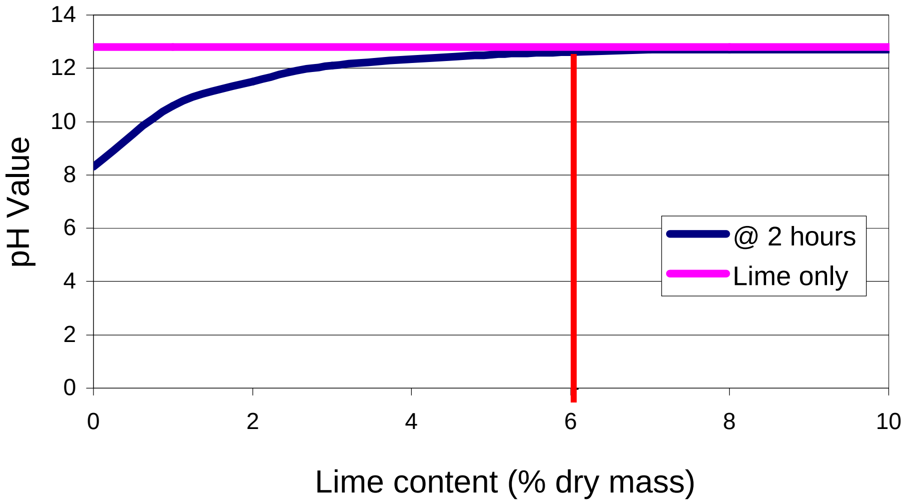

Figure 2 Lime content versus pH value based on Eades and Grim Test method (Killarney road trial pavement).

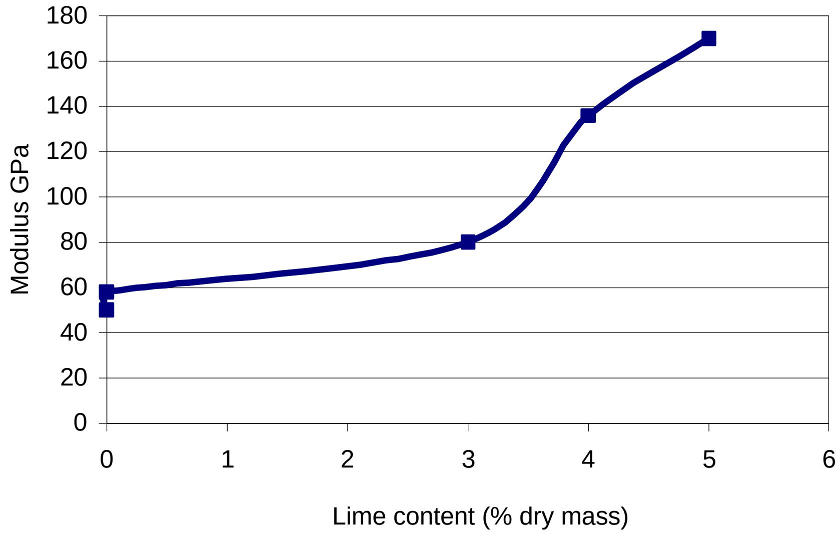

Figure 3 Modulus data (derived from CIRDEF after 6 months) from the Killarney Road trial.

Figure 4 Lime stabilisation mixing of the Killarney Road project, Warwick.

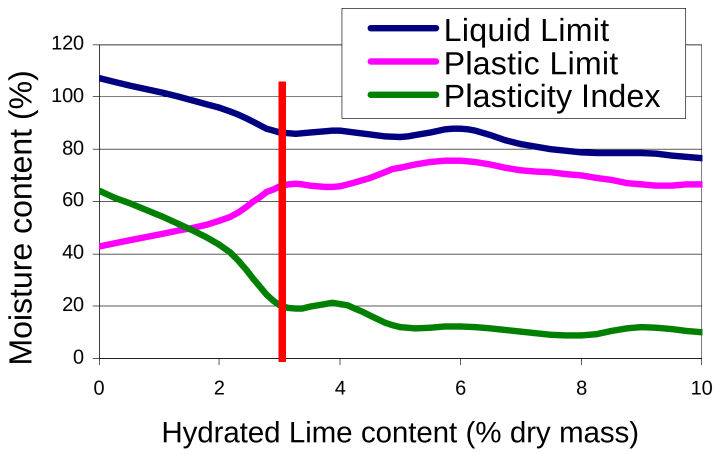

Figure 5 Lime content, based on lime fixation, versus liquid limit, plastic limit and plasticity index for Cunningham Highway, Warwick.

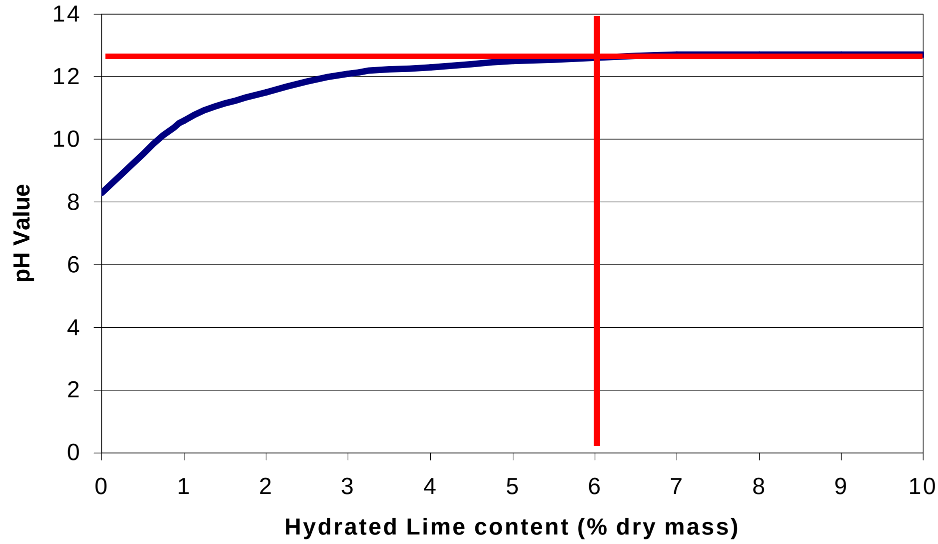

Figure 6 Lime content (based on lime demand) versus pH value for Cunningham Highway, Warwick trial pavement.

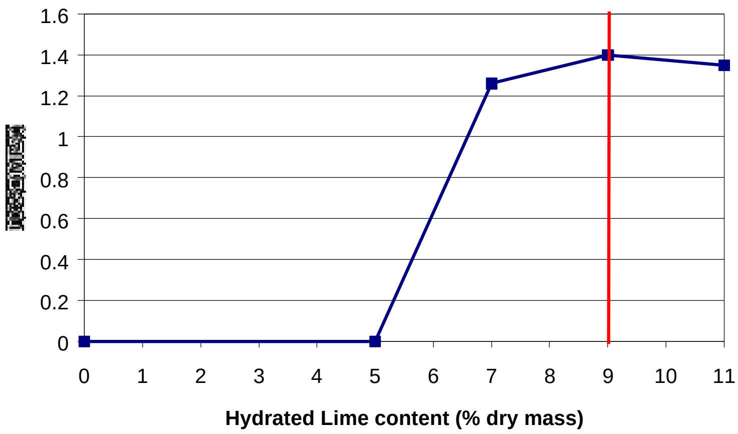

Figure 7 Lime content versus 28-day UCS based on Thompson's method for Cunningham Highway, Warwick trial pavement.

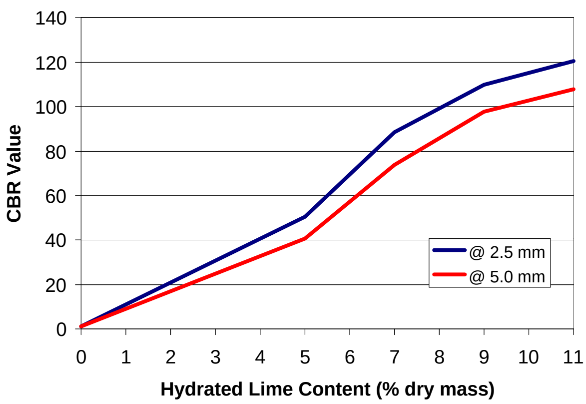

Figure 8 Lime content versus laboratory soaked CBR values.

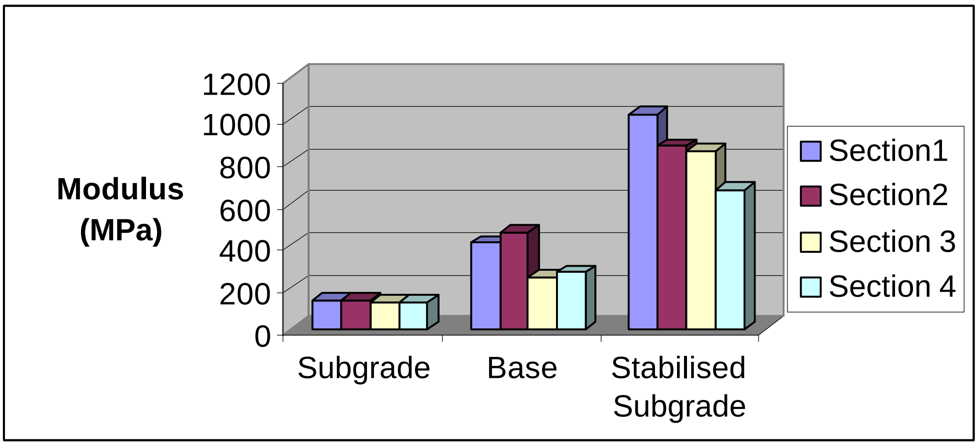

Figure 9 Back analysed modulus data at 6 weeks.

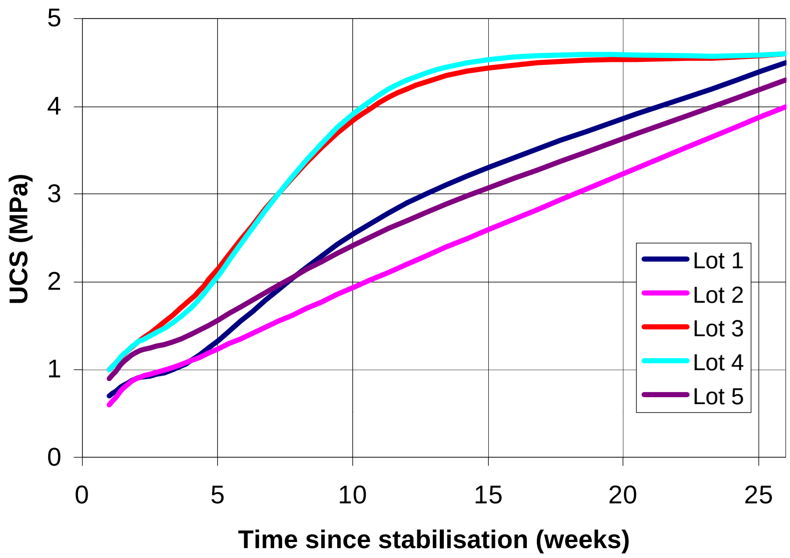

Figure 10 UCS data – cylinders taken during stabilisation process.

[END]