A LABORATORY STUDY TO INVESTIGATE THE DEVELOPMENT OF STIFFNESS IN STABILIZED MATERIALS

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ABSTRACT

The development of stiffness of stabilized materials with time is critical to the construction process, particularly in the case of recycling, where traffic is often required to return to the recycled road soon after construction. However, little information in this regard is available. A secondary problem is the difference in stiffness gain between different stabilizer types. Small field and laboratory investigations in which three sections of stabilized material using lime, CEM II B-V 32,5R and CEM V A (S-V) 32,5N were constructed, regularly monitored and tested over a period of 22 and 140 days respectively. The in situ stiffness was determined using a Lightweight Deflectometer (LWD) and a Portable Seismic Pavement Analyser (PSPA) on sections that were covered and prevented from drying as well as sections exposed to the air. The investigation thus also included the effects of drying and carbonation.

1 INTRODUCTION

The development of early stiffness of stabilized materials in roads with time is critical to the construction process. This is especially true in the case of in situ recycling, where construction is done in half-widths and traffic is often required to return to the recycled portion as soon as possible after construction. However, little information regarding the rate of strength gain in situ is available. A secondary problem currently being experienced is the difference in stiffness gain between different stabilizer types (Paige-Green & Netterberg, 2003). A small laboratory investigation in which three small sections of stabilized material using lime, CEM II B-V 32,5R and CEM V A (S-V) 32,5N were constructed, has been regularly monitored and tested. The in situ stiffness was determined using a Lightweight Deflectometer (LWD) and a Portable Seismic Pavement Analyser (PSPA) on sections that were covered and prevented from drying as well as sections exposed to the air and thus including the effects of drying and carbonation.

This paper discusses the preliminary findings of investigation.

2 BACKGROUND

Numerous problems have recently and are still being experienced with the construction of cement stabilized pavement layers. These vary from the duration of the actual mixing and compaction process, poor curing techniques, the use of incorrect cement and not understanding the behaviour of the cement used.

With the implementation of the SANS 50197-1:2000 specification for cement in South Africa in 2000, a new range of cements with new classifications and nomenclature appeared on the market. Many Consultants and Contractors have still not come to terms with this specification and various problems arise as a result of the incorrect choice of cement for road stabilization. One of the particular problems is the availability of the different cements around the country. This has resulted, for instance, in only an R rated cement (i.e., developing a specified early strength) being available at a certain location when a N rated cement would normally be required. This can result in a reduced working time.

One of the objectives of this investigation was to assess the difference in rate of stiffness development between typical R and N cements in comparison with lime and to assess the actual stiffness values that could be developed under typical construction conditions. For this purpose, bags of road lime, CEM II B-V 32,5R and CEM V A (S-V) 32,5N were obtained from local suppliers.

3 EXPERIMENTAL WORK

Two experiments have been carried out using the above stabilizers, an initial one in the field and a subsequent one in the laboratory. Although the field experiment was designed to minimise the effects of moisture changes in the subgrade, it was found that any rain showers that occurred appeared to have an impact on the stiffness of the stabilized material by causing changes in the stiffness of the underlying subgrade. For this reason the second experiment was designed in an enclosed laboratory space such that the "subgrade" conditions were constant.

Both experiments were constructed using the same material, a red-brown, natural hillwash silty sand from the CSIR campus in Pretoria. The material had 100% passing the 2mm screen and 15 to 21 % finer than 0.075 mm. CBR values varied between 40 and 70 % and the material was slightly plastic to having a Plasticity Index of about 6%. The Optimum moisture content was about 9% and the maximum dry density at 100% Mod AASHTO compaction was 2040 kg/m^3. 3% of each of the respective stabilizers was mixed into each batch of material.

After compaction, the sections were tested to provide a baseline value and then covered with a plastic sheet and allowed to cure for 7 days (monitoring continued during this time). After 7 days, the plastic sheeting was rolled back exposing about 30 per cent of each section to the atmosphere. This left a section that ostensibly continued normal curing (covered) and a section that was allowed to cure, dry and carbonate simultaneously (uncovered). The intention of this was to allow the material to dry back naturally to determine whether there was any effect on the curing of the material. It was also expected that the exposed areas would be subject to more carbonation.

3.1 Field Experiment

The field experiment was carried out during February and March 2009 at the Built Environment experimental site on the CSIR campus. The in situ material was scraped clear of topsoil and organic matter and nominally compacted. Shuttering was used to construct the individual sections, but an error in the contractor's mass estimation resulted in layers that were thinner than planned after compaction. The panels were separated by cardboard dividers. Despite the thickness problems, monitoring of these sections was carried out for about 30 days.

3.2 Laboratory experiment

For the laboratory experiment, a wooden formwork was built that allowed a 1 m by 1m by 100 mm thick layer of stabilized material to be constructed on a plastic sheet directly over the thick concrete laboratory floor. This allowed full control of the material density (compaction) and subgrade conditions, as well as eliminating the influence of any rainfall. The wooden formwork included shuttering to ensure that the layers were compacted to 100% Mod AASHTO density with each panel being separated by a wooden strip. The experiment was monitored between June and November 2009.

3.3 Monitoring

The stiffness's of the sections over time were monitored using a Lightweight Falling Weight Deflectometer (LWD) and a Portable Seismic pavement Analyser (PSPA). The LWD operates on exactly the same principles as a conventional Falling Weight Deflectometer (FWD) but uses a smaller falling mass (10 kg) and was configured to measure the peak deflection beneath the falling mass and convert this to a stiffness of the layer being tested.

The PSPA is a small apparatus that monitors the arrival times of a small seismic wave after travelling over a distance of up to 300 mm (Steyn and Sadzik, 2007). Although the main objective of the testing was to assess the strength gain of the materials with time, a secondary objective was to compare the stiffness of the material at various times using the two different monitoring methods. The PSPA data used in the field test section extended to a depth of between 500 and 800 mm although the depth of validity of the equipment is a function of the frequency setting (lower frequencies penetrate deeper into the structure and vice versa). It would also be a function of the spacing between the source and the receiver, but this is fixed at 300 mm on the PSPA. For the laboratory experiment, the average seismic stiffness between 40 and 105 mm depth was determined on each panel.

Each of the sections (both covered and uncovered) was marked at specific points for testing to ensure that exactly the same positions were tested each time. Testing with the LWD involved the application of 4 drops of the mass. The first drop acts as a seating blow and measurements from this are discarded. The measurements from the following three blows are then monitored to ensure a measure on consistency before the average of the three readings is calculated and used as the final value (the possible effect of compaction by the 4 blows on the reading has not been quantified). Testing with the PSPA was carried out with triplicate tests in two directions perpendicular (longitudinal and transverse) to each other but with the seismic pulse applied at the same point.

An estimate of the pH and carbonation of each of the sections was obtained using phenolphthalein and hydrochloric acid each time the stiffness was measured.

The air and soil temperatures were monitored using Thermochron Temperature iButtons recording at 15 minute intervals for the field test and one hour intervals for the laboratory experiment.

At the end of the experiment, the materials were removed from the panels and samples collected for density, moisture and strength/stiffness testing. The densities were determined using the wax method on lumps removed from the panels.

4 RESULTS

4.1 Test-site experiment

This experiment ran for about 35 days during which the air and soil temperatures varied between 15 and 40°C and 22 and 34°C respectively, probably typical of summer conditions over much of South Africa. The rainfall was not monitored.

The results of the PSPA testing were highly variable with no trend in either time or stiffness. Figure 1 shows an example of the covered lime treated panel. The stiffness in the treated layer varied between about 1 and 29 GPa during the monitoring period. Of greater concern is the fact that the first monitoring yielded the second highest stiffness in the stabilized layer and the last monitoring yielded one of the lowest stiffness's. Similar trends were shown for all of the panels, the results of the early strength (R) cement being illustrated in Figure 2.

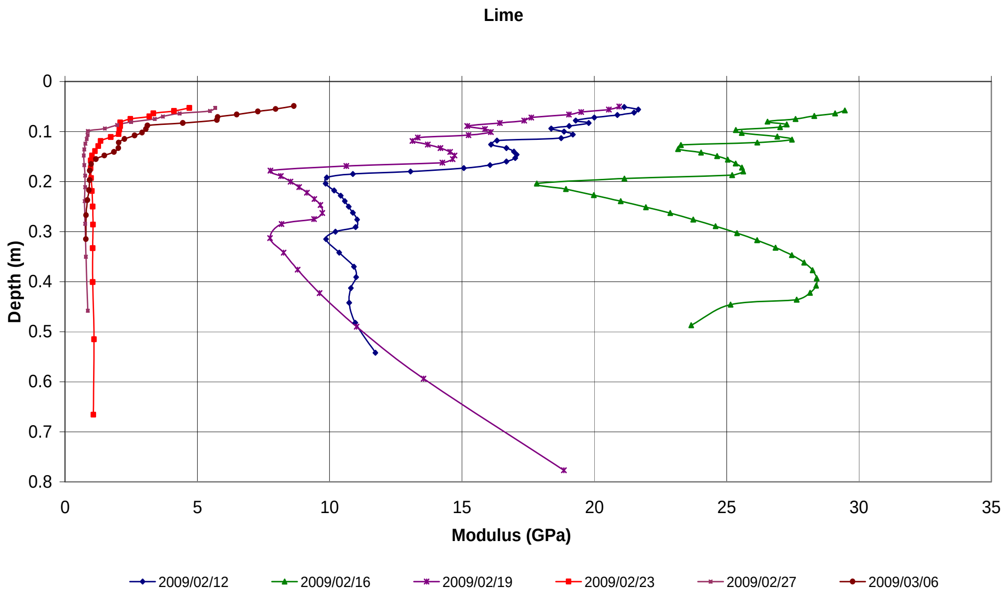

Figure 1: Typical PSPA test result on field lime stabilized material.

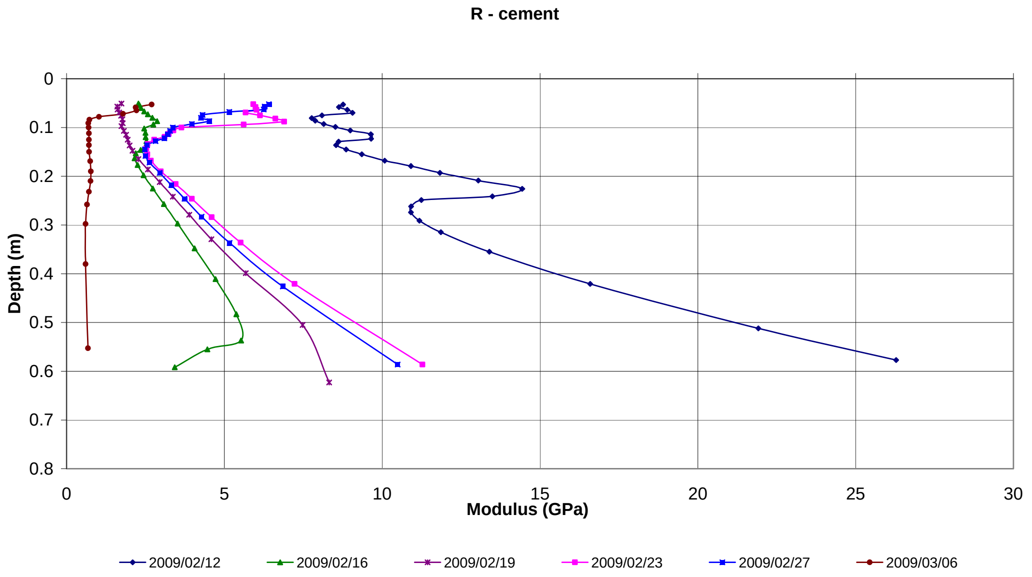

Figure 2: Typical PSPA test results on field cement (R) stabilized material.

The results of the LWD gave somewhat better results as illustrated in Figure 3 for the covered lime, R-cement and N cement sections. It is interesting to note that the stiffness values measured are considerably lower than those obtained from the PSPA, but other than the N-cement the stiffness gain with time was relatively small over the monitoring period.

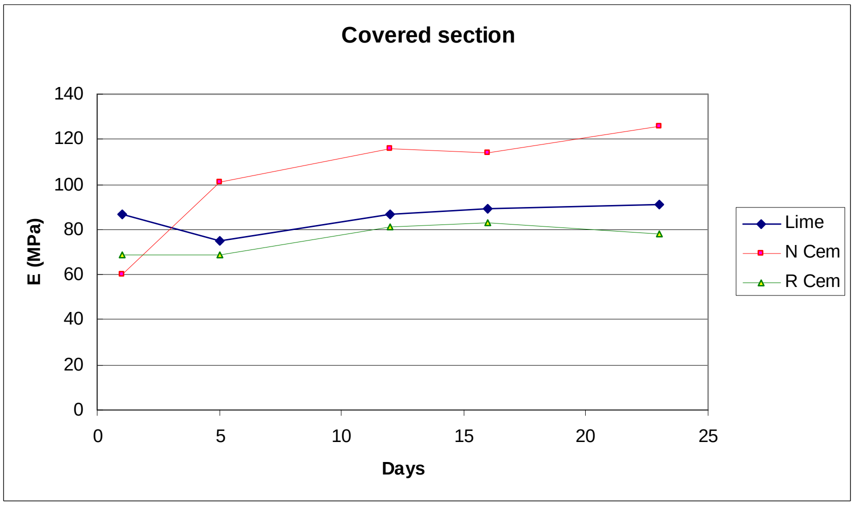

Figure 3: LWD results on covered stabilized panels

4.2 Laboratory experiment

This experiment ran for about 140 days during which both the air and soil temperatures were between 12 – 25°C.

The PSPA testing for this experiment involved determining only the average stiffness between depths of 40 and 105 mm. The results were analysed in a number of ways, with the mean of the two closest values in each direction being used for the final analysis. The results for the covered (cured) and uncovered (carbonated) sections are summarised in Figures 4 and 5 respectively.

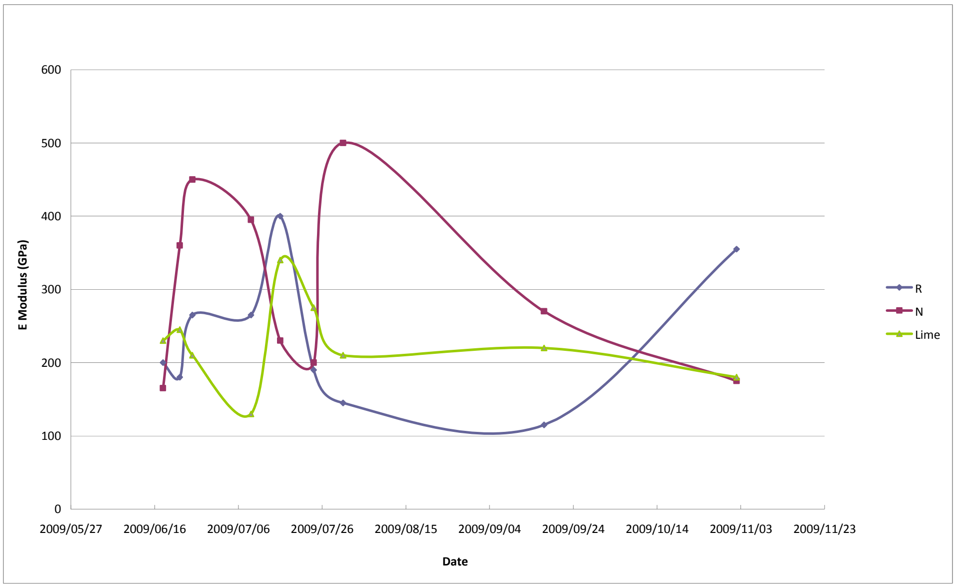

Figure 4: PSPA results for covered panels in laboratory investigation

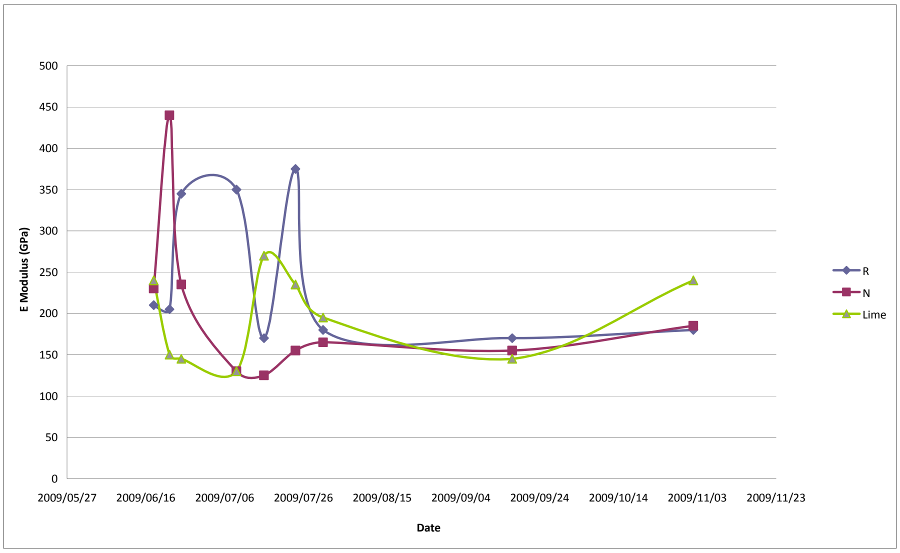

Figure 5: PSPA results for uncovered panels in laboratory investigation

As was the case in the field experiment, the results are somewhat erratic with no simple trends of increasing stiffness with time (it is considered that the high modulus of the underlying concrete could have affected the results). Large variations in stiffness during the first 5 or 6 weeks characterise both plots. It is also possible that the results were erratic due to the high sensitivity of the PSPA apparatus. The sensors are highly sensitive and could react to any vibrations that occur in the immediate area during testing.

The LWD results appeared to be more realistic (Figures 6 and 7) although they were much higher than the field results. There are general trends of increase in stiffness with time, although they are not necessarily consistent. The effect of the underlying concrete could also have influenced these results, although it would be constant throughout the testing period. It is interesting to note that the increase of stiffness of the lime sections was faster than the R-cement in both cases.

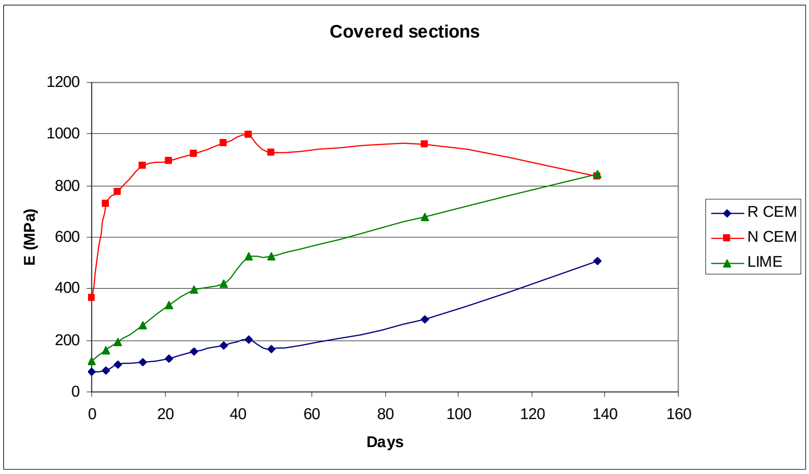

Figure 6: LWD data for covered sections in the laboratory

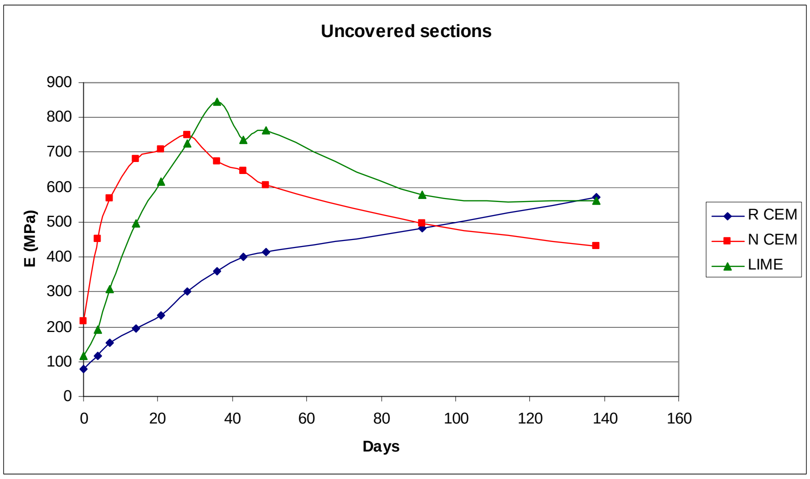

Figure 7: LWD data for uncovered sections in the laboratory

Visual phenolphthalein and hydrochloric acid testing was done on all panels during each monitoring. The results are summarised in Table 1.

Table 1: Phenolphthalein and hydrochloric acid reactions (strong indicates little or no carbonation)

Panel	**Day 1**		**End of experiment**	
	Phenolphthalein	**HCl**	**Phenolphthalein**	**HCl**
Lime covered	Strong	Yes	Strong	Yes
Lime uncovered	Strong	Yes	None	Yes
N-cement covered	Weak	Yes	Strong	Yes
N-cement uncovered	Weak	Yes	None	Yes
R-cement covered	Weak	Yes	None	Yes
R-cement uncovered	Weak	Yes	None	Yes

At the end of the experiment, the full depths of each of the samples were sprayed with phenolphthalein (Figure 8) and the results indicated various depths of carbonation from the surface.

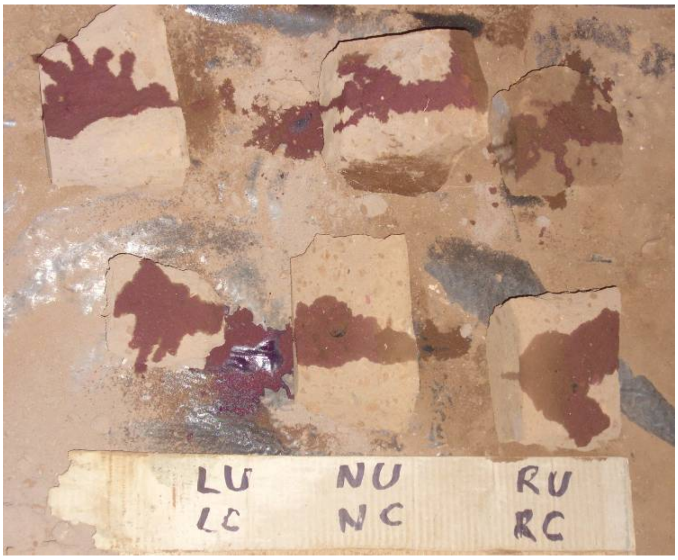

Figure 8: Phenolphthalein reaction on the extracted samples (L – lime, N – Normal cement, R – early strength cement, U – uncovered, C – covered : a dark red colour indicates a high pH)

The density (wax coated) and moisture content as well as the pH of each of the materials were also determined. The results are summarised in Table 2.

Table 2: Density, moisture content and pH of samples at end of experiment

Panel	Density (kg/m^3)	Moisture content (%)	pH
Lime covered	1985	4.0	12.9
Lime uncovered	2014	0.7	12.9
N-cement covered	1892	5.6	11.7
N-cement uncovered	1827	1.6	11.7
R-cement covered	1912	5.0	11.4
R-cement uncovered	1940	0.7	10.6

Cubes with 100 mm dimensions were cut from the material removed from the panels and subjected to Unconfined Compressive Strength (UCS) testing (Figure 9) with simultaneous measurement of the axial deformation. Testing was carried out in duplicate or triplicate depending on whether sufficient suitable samples could be prepared. This allowed the determination of the stiffness (secant modulus at failure) of the material for comparison with the final stiffness measured in the panels. A number of the blocks failed during handling but some results were obtained for each material. The results are summarised in Table 3.

Figure 9: Examples of cubes after UCS testing (triplicate tests on covered N cement cubes)

Table 3: Strength and stiffness of cubes removed from panels (mean of duplicate or triplicates tests)

Panel	Mean UCS (kPa)	Mean E-modulus (MPa)
Lime covered	43	8.7
Lime uncovered	33	7.4
N-cement covered	654	121.5
N-cement uncovered	335	33.8
R-cement covered	431	21.8
R-cement uncovered	333	16.2

5 DISCUSSION

Despite having a better controlled experiment indoors and under laboratory conditions, there was little improvement in the data obtained. The LWD results appeared to show better trends than the PSPA with a general increase in stiffness with time. The PSPA results show no trend. It was initially thought that the depth of influence of the PSPA would be considerably less than the LWD, although the results do not support this. Even the variation in the PSPA results on rotating the apparatus through 90° was remarkably high and inconsistent (Figure 10).

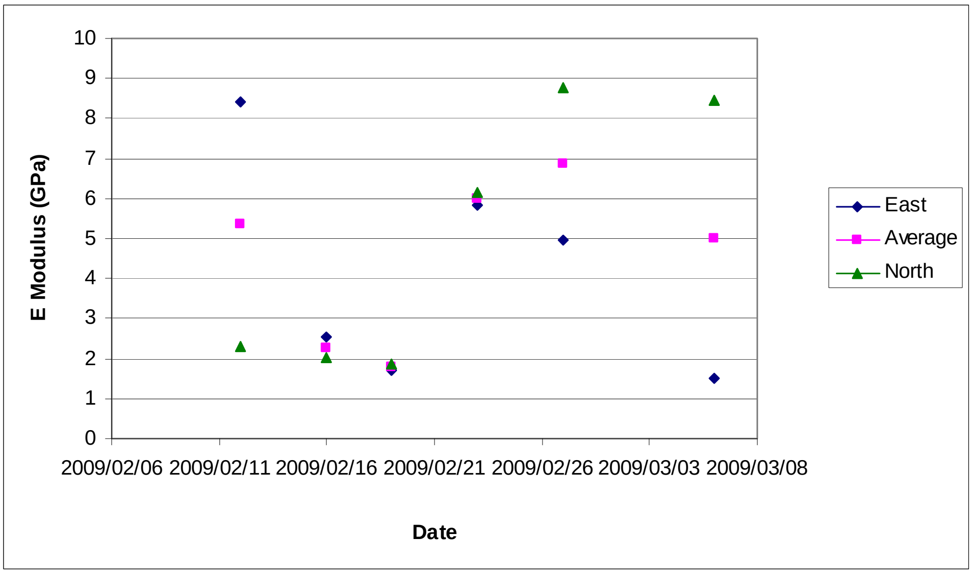

Figure 10: Variation in field experiment PSPA results after rotating (average of triplicate tests on covered lime treated section)

It is known that the seismic (low strain, high strain rate) stiffness values obtained using the PSPA are considerably higher than the stiffness values determined using traditional methods (e.g., FWD and LWD, which utilise high strain at low strain rates) (W Steyn, pers comm, 2010). Despite this, the stiffness values measured using the LWD were generally in the range 90 to 1000 MPa in the laboratory experiment (75 to 900 MPa in the first 21 days) and 60 to 125 MPa in the field experiment, probably the result of the large differences in the moduli of the underlying materials. The PSPA stiffness's were considerably higher, generally in the range 1 to 29 GPa. Traditionally a C4 cemented material in the precracked stage would be expected to have a stiffness of about 3 500 MPa and in the equivalent granular phase of 300 to 500 MPa (Maree and Freeme, 1981). The laboratory LWD experiment results are generally within the equivalent granular range, but one would expect somewhat higher stiffness's than this.

The rates and patterns of curing of the three stabilizers determined using the LWD varied considerably. The field experiment showed the N-cement section to double in stiffness over the first 22 days while the lime and R-cement hardly changed. In the laboratory experiment, the N-cement tripled in stiffness during the first 40 days under covered curing and then appeared to increase no further. The stiffness of the lime and R-cement increased much slower, the lime panel ending with a similar stiffness to the N-cement after 140 days and the R-cement being only about 60% of this. It is notable that the R-cement had no significantly faster early stiffness gains.

In the uncovered sections the results are a little more difficult to interpret as there are essentially three processes affecting the normal strength (and by implication, stiffness) development. These are the effect of normal hydration of the stabilizer (increasing the strength), the effect of carbonation of the material (decreasing the strength) and the effect of drying out of the material (increasing the strength). It is not possible to separate these influences on the stiffness in an experiment such as this. The N-cement increased in stiffness for the first 30 days and then showed a gradual decrease. The highest stiffness achieved was less (25%) than in the covered panel. The R-cement continued to gain stiffness over the full 140 days, ending up stiffer than the covered panel. Assessment of the carbonation (Figure 8 and Table 2), however, showed that this panel was the most carbonated and the stiffness gain can thus probably be attributed more to drying of the material. The lime panel behaved similarly to the N-cement, although the maximum stiffness attained was higher than that in the covered sections.

Assessment of the laboratory Unconfined Compressive Strengths and stiffness's of the materials gave mixed results. However, it is clear that the strengths and moduli are lower than required for a C4 material. This is because the virgin material was of low quality and would not normally be used for stabilization, combined with the relatively low stabilizer content. The following points can be deduced from the results, however.

- There is a significant decrease in UCS and stiffness between the covered and uncovered panels – this could result from both carbonation and incomplete hydration during the cementitious reactions.
- The N-cement appeared to provide better stabilization than the R-cement, while the lime was, as expected, relatively ineffective on the low plasticity material.

6 CONCLUSIONS

The general outcome of these experiments can be considered to be inconclusive, although some useful information was obtained. The monitoring devices used appear to be unsuitable for this type of work: they could probably be more useful with considerably thicker constructed panels. The LWD shows some promise, but it is unknown whether the possible compaction effect of repeated testing at the same point has any effect on the results. It is also important in this type of study to better understand the depth of influence and zone of measurement of monitoring devices used.

One of the objectives of the experiments was to assess the stiffness development process, but mixed results were obtained. Surprisingly, the N-cement and lime increased in stiffness quicker (and better) than the R-cement but appeared to be more prone to losing their strength and stiffness on carbonation. It was also interesting to note that the N-cement appeared to achieve its maximum stiffness after about 40 days, whereas the lime and R-cement continued to gain in stiffness continually for 140 days and appeared to be continuing to increase at 140 days. The UCSs and stiffness's of the material specimen blocks at the end of the experiment indicated that the N-cement provided the highest values, but also appeared to be the most prone to carbonation.

It is recommended that a similar experiment should be carried out using more traditional road construction materials and different monitoring techniques.

7 ACKNOWLEDGEMENTS

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