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The performance of unpaved road material using soil stabilisers

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There are over 500 000 km of unsealed roads in South Africa. Unacceptable levels of dust, poor riding quality and impassability in wet weather are experienced on much of this road network. A potential solution to this ever-increasing problem is the use of soil stabilisers (additives), yet the level of research done on these additives consists mostly of small ad hoc studies.

The aim of this paper is to report on the performance of selected soil stabilisers used on South African unpaved roads with respect to their effect on material strength. The behaviour of the soil stabilisers were tested by determining the effectiveness of the stabilisers in improving the strength of unpaved roads as a function of gravel with different properties for a range of soil stabilisers under wet and dry conditions. The effectiveness was tested over a period of nine months. Four different stabilisers were used on four different wearing-course materials.

The conclusion reached was that there are certain stabilisers that do improve the strength behaviour of pavement material under certain conditions. It was found that the enzyme and sulphonated oil-treated materials had an increase in strength over the test period, and it was concluded that these stabilisers need a curing time of a few dry months to reach their maximum strength. The materials treated with the two polymers gained their maximum strength within two months after construction. It was found that the enzyme-treated material showed an increase in strength when applied to a sandy material with a low PI and the sulphonated oil-treated material performed well when applied to a clayey material containing a reactive clay mineral. The polymers showed no material-specific properties.

Most of the stabilised panels showed an increase in dry strength eight months after construction and this was attributed to the fact that the panels had enough time to dry out and reach their maximum strength over the dry winter months.

The final conclusion was that there are some soil stabilisers available that do improve the strength behaviour of pavement materials. It is, however, important to choose the correct stabiliser for the intended purpose.

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INTRODUCTION

There are over 500 000 km of unsealed roads in South Africa. Service roads belonging to rail authorities and electricity and telecommunication providers, and forestry roads are not included in this total. Unacceptable levels of dust, poor riding quality and impassability in wet weather are experienced on much of this road network (Jones & Ventura 2003).

It is estimated that approximately three million tonnes of dust are generated on South Africa's unsealed road network every year. It is assumed that two thirds of this dust resettles on the road and that one million tonnes of material are permanently lost from South African unsealed roads (Jones & Ventura 2003). Not only does this lead to reduced quality of life and an increased safety hazard, but it also results in accelerated gravel loss and more rapid deterioration of the surface area of the unpaved road. Lost paving material will more frequently need to be replaced and grader maintenance applied (Foley *et al* 1996). Another worrying factor is that the frequent replacing of gravel is unsustainable as natural resources are being depleted (Jones & Ventura 2003). Since the movement of people and goods can be severely hampered during the wet season, all-weather passability is important to road users and authorities.

A potential solution to this ever-increasing problem is the use of soil stabilisers (additives). Over the last 25 years, numerous additives have been introduced to the road industry in South Africa, yet the research done on these additives consists mainly of very limited studies. A large number of experimental and demonstration sections have been constructed and laboratory tests done by companies on their own additives; however, these have been poorly controlled and little has been reported in literature, especially with regard to costs and benefits. This has led to suppliers of road additives seldom being able to provide sufficient information to road authorities and engineers to make a decision on the appropriate use of these products instead of using more conventional stabilisers in a more expensive design (Jones & Ventura 2003).

There is thus a big gap in the field of study of soil stabilisers and a major need exists for reliable data on the performance of soil stabilisers for unpaved roads, especially field test results taking into consideration all the variables that exist during construction on South African roads. This research is imperative to ensure that the future construction and maintenance of unpaved roads ensure an acceptable level of service for all road users, within the limited budget available to road authorities, while protecting the environment in terms of dust formation and gravel loss.

The aim of this paper is to report on the performance of selected soil stabilisers used on South African unpaved roads with respect to their effect on material strength. The behaviour of the soil stabilisers were tested by determining the effectiveness of the stabilisers in improving the strength of unpaved roads as a function of gravel with different properties for a range of soil stabilisers under wet and dry conditions. The effectiveness was tested over a period of time to determine at what point the treated pavement material reached maximum strength and if any immediate deterioration in strength behaviour was evident. Effectiveness is a function of comparing the improvement in strength gained by using different additives on pavement material against the material without the use of an additive.

ROLE OF STABILISERS ON UNPAVED ROADS

TRH 20 (1990) mentions the typical defects which may affect unpaved roads, such as dustiness, potholes, stoniness, corrugations, ruts, cracks, ravelling, erosion, slipperiness, impassability and loss of surfacing or wearing course. The soil properties that require alteration to prevent the effects mentioned above include:

- Strength to increase stability and bearing capacity
- Volume stability to control swelling/shrinkage caused by changes in moisture content
- Durability to increase resistance to erosion either from weather or traffic
- Reduction in permeability, that is, reduce the ability of water to enter and pass through the soil

Of these soil properties the most important wearing course material parameter is strength (bearing capacity). This leads to four aspects that must be satisfied with regard to the selection of materials – and potential improvement by adding a soil stabiliser – for low-volume roads They are (Department of Transport 1993):

- Adequate bearing capacity under any individual applied load
- Adequate bearing capacity to resist progressive failure under repeated individual loads
- The ability to retain that bearing capacity with time (durability)
- The ability to retain bearing capacity under various environmental influences (which relates to material moisture content and in turn to climate, drainage and moisture regime)

In many cases a contractor will apply an additive to perform a duty it was not designed for. To prevent this from happening and ensure an understanding of the different additives available and their limitations, unpaved road additives must be categorised in terms of function.

SOIL ADDITIVE CATEGORIES

There are two reasons for using soil additives on unpaved roads, namely dust suppression, leading also to erosion prevention, and strength improvement. Soil stabilisers used for dust suppression are referred to as dust palliatives, and for strength improvement as stabilisers. Both of these categories can then be subdivided into categories of additives available on the market (Jones & Ventura 2003):

- Dust palliatives
  - Water and wetting agents
  - Hygroscopic salts
  - Natural polymers
  - Synthetic polymer emulsions
  - Modified waxes
  - Petroleum resins
  - Tars and bitumens
  - Other (various products that are usually waste products)
- Stabilisers
  - Synthetic polymer emulsions
  - Sulphonated oils
  - Enzymes and biological agents
  - Lime and cement
  - Tars and bitumens

By using a stabiliser, the pavement material is able to retain particles finer than 0,075 mm. The fine aggregate held in place in its turn secures the larger aggregate sizes and the road surface is more resistant to the formation of loose aggregate on its surface, which, if formed, would be swept away by the action of traffic. This is most commonly noticed as a large dust cloud behind vehicles travelling on the road. When material is eventually swept away on a stabilised road, a fresh layer of densely graded material is exposed to recommence the process of attrition (Foley *et al* 1996). In other words, a stabiliser is also a dust palliative and along with strengthening the unpaved road surface the stabilising material can also prevent dust formation.

ADDITIVES USED

- The aim of this study was to acquire reliable data on the strength behaviour of soil additives on unpaved roads, and therefore only stabilisers were used. However, the number of stabilisers was limited because of logistics and costs. It was decided not to include traditional stabilisers such as lime, cement or bituminous products in the study because of the large amount of testing done and available experience on these stabilisers. Traditional stabilisers such as cement and bitumen are also too expensive to use on the majority of unpaved roads in South Africa, and a comparison with the stabilisers used would have been of no value. It was decided to use two polymer emulsions, a sulphonated oil and an enzyme.

The origin of these soil stabilisers is given in table 1.

Table 1 Characteristics of soil stabilisers

Soil stabiliser	Origin
Polymer A	South Africa
Polymer B	United Kingdom
Enzyme	USA
Sulphonated oil	South Africa

Polymer emulsions are suspensions of synthetic polymers in which the monomers are emulsified in a dominantly aqueous medium that polymerises on evaporation of the water. Interim laboratory and field tests have shown that this group has potential as a stabiliser on unsealed roads, although certain products are susceptible to weakening when wet.

Sulphonated oils consist primarily of strongly acidic sulphur-based organic mineral oils. The two properties that make sulphonated oils useful in soil stabilisation are their ability to displace and replace exchange cations in clay and to waterproof clay minerals by displacing the absorbed water and preventing re-absorption. However, in order for a cation exchange reaction to occur, it is necessary for a suitable clay component to be present in the material. This action is shown in figure 1.

Enzymes lower the surface tension of water, thereby acting as a compaction aid in most soils. The manufacturers also claim that the enzymes extract mineral traces from the soil, leading to a crystallisation process that creates bonds between adjacent soil particles, as shown in figure 2. This improves the soaked strength of the soil and hence the wet-weather passability.

Table 2 Materials summary

Material	Type of material	Grading modulus	CBR at 95 % MOD AASHTO	TRH 14 classification at 95 % MOD AASHTO	CBR at 90 % MOD AASHTO	TRH 14 classification at 90 % MOD AASHTO	Liquid limit (%)	Plasticity index (%)
Daveyton	Windblown sand	0,85	20	–	7,0	G10	15	4
Benoni	Weathered dolerite	1,65	10	–	3,9	G10	28	11
Quantam	Gravel	1,95	24	G7	8,3	–	30	12
Putfontein	Ferricrete	2,01	7,6	–	5,3	G10	27	10

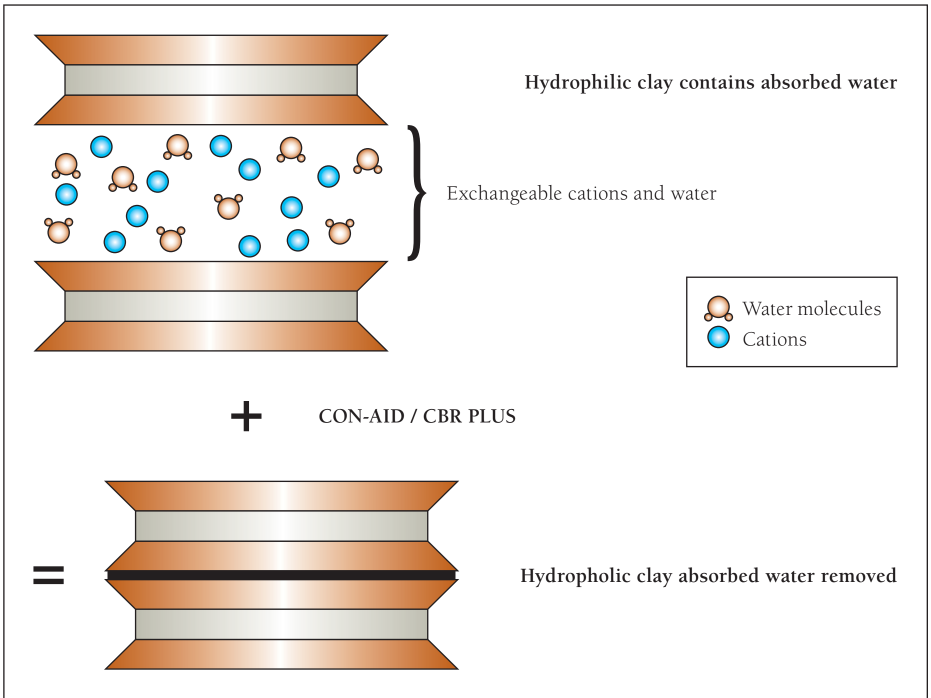

Figure 1 Reaction of clay particle with sulphonated oil (www.cbrplus.co.za)

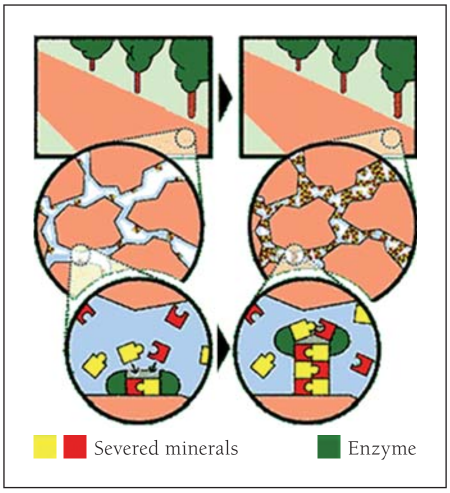

Figure 2 Enzyme substructure (www.PERMA-ZYME11X.com)

The following application rates, as recommended by the manufacturer, were used for each soil stabiliser:

- Polymer A – 0,75 ℓ/m² for 150 mm thick layer
- Polymer B – 0,25 ℓ/m² for 150 mm thick layer
- Enzyme – 0,005 ℓ/m² for 150 mm thick layer
- Sulphonated oil – 0,01 ℓ/m² for 150 mm thick layer

The manufacturers of polymer A recommended that a final application of the product should be made after compaction of the layer, to act as a sealant. The manufacturers of the sulphonated oil specified that their product gives the best results on a material containing a reactive clay mineral, and with the enzyme the suppliers have found that it gives the best results on a sandy material. The suppliers of polymer A and polymer B gave no material-specific recommendations.

EXPERIMENTAL DESIGN

In the experimental design selected four stabilisers could be tested on four different materials, as well as a range of material properties. An untreated material of each type was used as a control material. Test panels were constructed to obtain test results from the soil stabilisers under normal field conditions relating to the construction of the panels and the climatic conditions experienced. The panels were constructed so that no traffic would pass over them. It was realised that traffic plays a major role in field conditions, but it was concluded that the effects of the construction process and climatic conditions on the strength behaviour must first be determined before the behaviour relating to traffic loading and movement could be looked at. This in itself will consist of an entire study.

The test site was constructed in Benoni in the Ekhurhuleni municipal district, with the assistance of the Ekhurhuleni Metropolitan Municipality. Ekhurhuleni is situated on the East Rand in Gauteng.

It was decided to construct test panels for the purpose of this study. The panels were 1 m wide, 3 m long and 0,15 m thick. All the stabilisers were added, mixed into the material and allowed to soak into the material. After the application of the soil stabilisers and thorough mixing of the material, the panels were compacted in 50 mm layers with eight passes of the Bomag BW 65 S-2 walk-behind roller.

The following tests were undertaken during this study:

- Determining the characteristics of the materials obtained from the borrow pits according to TMH1
- Determining the strength performance of the in-situ stabilised pavement materials and the comparison with an untreated material over time by means of the dynamic cone penetrometer (DCP)
- Determining the stabiliser characteristics that led to the strength performance with the help of the Marvil permeameter and the scanning electron microscope

The DCP measures shear strength and can give a good correlation with respect to the CBR, but it should be kept in mind that this is only a correlation and not the exact CBR. For this study the strength behaviour over time and between the different stabilisers were compared and the aim was not to determine the exact CBR obtained by using a certain stabiliser with a certain material. It was therefore concluded that the DCP will be the most suitable instrument to use as it can determine the in-situ shear strength with the least amount of disturbance to the test panel.

The use of the scanning electron microscope was an experimental approach and no concrete results were obtained from this test method; therefore the results will not be discussed in this report. However, it was concluded that in further studies the

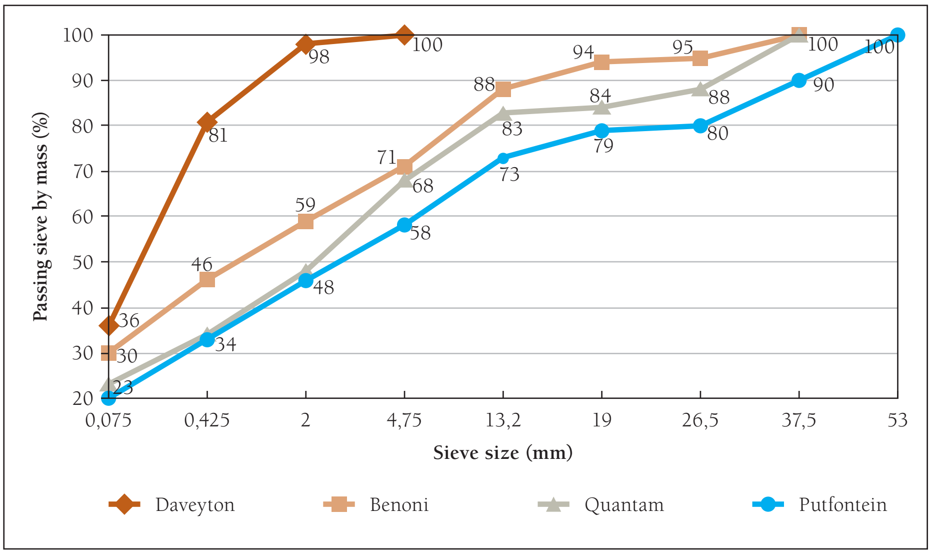

Figure 3 Grading curves for the material to be used

electron microscope can play an important role in examining the strength behaviour of soil stabilisers.

The soil properties of the four materials used during this study are given in table 2.

From the laboratory test results, and the fact that these materials will represent the wearing course of the unpaved road, it can be concluded that the pavement materials used in this study all had a low PI and LL. In the experimental design a wider range of properties was desired, but on sourcing the materials typically used in the region a smaller range was found. Furthermore, from the soil mortar the following conclusions can be made:

- Daveyton was a silty sand with 46 % of the fine material's size being between 0,075 and 0,425 mm, and 17 % between 0,425 and 2 mm
- Benoni and Putfontein were very silty clays, with respectively 44 % and 51 % of the fine material's size being less than 0,075 mm
- Quantam was a sandy gravel that had a high percentage of fine material less than 0,075 mm (48 %), and a high percentage of fine material between 0,425 and 2 mm (29 %)

Figure 3 shows the grading curves for the sieve analysis results.

From figure 3 it can be concluded that:

- The Daveyton sand was fine graded
- The Quantam clayey sand was well graded
- The Benoni clay was well graded, with a higher percentage of fine material
- The Putfontein clay was well graded, with a slightly higher percentage of coarse material than Quantam and Benoni

X-Ray diffraction (XRD) tests were also done on the Putfontein and Benoni materials. From the test results the conclusion was made that the Benoni material contained an active clay. A peak was found that indicated that montmorillonite, a smectite clay, was present. Montmorillonite is an active clay with hydrophilic properties. Such a clay was not present in the Putfontein material.

It is well known that the major reason for failure in any pavement structure is water seepage. It is not possible to close a road after a rainstorm to let it dry out before vehicles can use it again and therefore it is important that an unpaved road has good wet weather passability. In other words, it is important to ensure that as little water as possible enters the unpaved road structure and that the pavement still performs well with the amount of water that did enter the pavement layer. Therefore, the DCP–CBR was determined at in-situ and soaked moisture conditions.

For the soaked test a third of a 200 ℓ steel drum was placed on the unpaved road surface and sealed around the edges. A depth of 50 mm of water was then poured into the drum and the level kept constant for two hours. After two hours the drum was removed and the CBR tested with the DCP. This test, seen in figure 4, was done to give an indication of the bearing capacity of the stabilised material that could be expected on the road after a heavy rainstorm. To be able to interpret the results obtained from this test and find out why certain panels performed better than others, the Marvil permeameter was used to determine the permeability of each panel and the Troxler nuclear density test was done to determine the density of each panel.

The tests were done over an eight-month period to determine the effect the stabilisers have on the strength behaviour of the pavement material over a period of time. For the first five months DCP tests were done each month and then again in month eight.

The area is a predominantly summer rainfall area and most of the rainfall occurs from September to March. The panels were constructed at the start of December 2004, during the rainy season. The total precipitation for the first five months of testing was 626 mm, which is high for the region. The panels were therefore tested under relatively wet climatic conditions for the first five months and tested under dry conditions in month eight, which was during the dry winter months.

Figure 4 Soaked DCP test (Visser & Erasmus 2005)

ANALYSING IN-SITU CBR ACCORDING TO RELATIVE COMPACTION OBTAINED

The CBR of the in-situ materials first was evaluated against the CBR determined from the laboratory tests. This made possible a comparison between the CBR of the material from tests done in a controlled environment and what was found during the field testing. The same compaction was applied to all the test panels during construction and no further compaction was done after construction. The panels were constructed on an existing road and it was considered that there were no differences in the supporting layer for all the test panels.

The target was to obtain a 95 % MOD AASHTO density for each panel, but from the test results it was found that the MOD AASHTO density of the different panels ranged from 81 % to 97 %, and that some panels had an increase in density and some a decrease over the five-month period between Troxler nuclear density tests. The wide range of densities may be ascribed to the fact that the subgrade was found to have a CBR of 3, and it may be that the subgrade support for the panels ranged in strength giving different amounts of support to the 150 mm layer when compacted. The stabiliser used may also have had an influence on the relative compaction obtained and may indicate that the stabilisers could be used as a compaction aid. There may also have been discrepancies during the testing. The in-situ density tests in May 2005 showed unexpected patterns, and a further set of density results were obtained. The second set of test results did not have any significant correlation with those of the first five-month test. It may be that, because so many DCP tests were performed on the panels at the five-month stage, the hole used for the density test was near a DCP hole, resulting in incorrect readings. However, it was concluded that there was a change in the densities over the five-month period after the first density tests, but that the test results did not show any significant trend and it was not possible to make any conclusions on the increase or decrease of the panels' densities. Note that traffic seldom travelled over the panels.

Table 3 CBR of control panels

Month	Material	Panel	% MOD AASHTO determined with Troxler	DCP-CBR		Lab-soaked CBR at 90 % MOD AASHTO	Lab-soaked CBR at 95 % MOD AASHTO	Approximate TRH classification
				In-situ	Soaked			
December	Putfontein	5	89,0 and 92,4		3	5,3	-	G10
January	Putfontein	5		6	5	5,3	-	
February	Putfontein	5		23	5	5,3	-	
March	Putfontein	5		15	4	5,3	-	
May	Putfontein	5		12	5	5,3	-	
December	Daveyton	10	84,9 and 87,4		3	7	-	G9
January	Daveyton	10		4	3	7	-	
February	Daveyton	10		16	4	7	-	
March	Daveyton	10		13	4	7	-	
May	Daveyton	10		14	4	7	-	
December	Benoni	15	93,8 and 93,4		4	-	10	G9
January	Benoni	15		17	5	-	10	
February	Benoni	15		72	7	-	10	
March	Benoni	15		56	7	-	10	
May	Benoni	15		31	5	-	10	
December	Quantam	20	91,1 and 91		5	8,3	-	G8
January	Quantam	20		7	5	8,3	-	
February	Quantam	20		36	6	8,3	-	
March	Quantam	20		27	6	8,3	-	
May	Quantam	20		27	5	8,3	-	

The preparation of the supporting layer and the construction of the test panels were done in accordance with what would happen during normal construction. It was therefore concluded that all the panels experienced the same compaction energy and that the results can be accepted with confidence. It has to be kept in mind that this study was not done to compare the soil stabilisers with each other to determine the effectiveness on each pavement material.

The average relative compaction densities of the Putfontein, Daveyton and Quantam control panels were about 90 % and that of the Benoni control panel about 95 %. The in-situ CBR of the Putfontein, Daveyton and Quantam control panels for the extent of the study was compared with the 90 % MOD AASHTO obtained during the laboratory tests, and that of the Benoni panel with the 95 % MOD AASHTO. The in-situ CBR of the control panels and CBR at 90 % MOD AASHTO and 95 % MOD AASHTO for Benoni of the pavement materials can be seen in table 3.

From the table it can be seen that the control sections reached their maximum in-situ CBR two months after construction. None of the panels had a higher soaked CBR than the CBR at the corresponding MOD AASHTO density during the laboratory tests. It was therefore decided to compare the dry CBR of the panels with the corresponding lab CBR. It was found that there was not a good correlation between the field and lab testing. This can be ascribed to the fact that the results from the DCP, when converted to CBR, only gives an indication of the CBR of the material and not the exact CBR, and confirms the comment made earlier on.

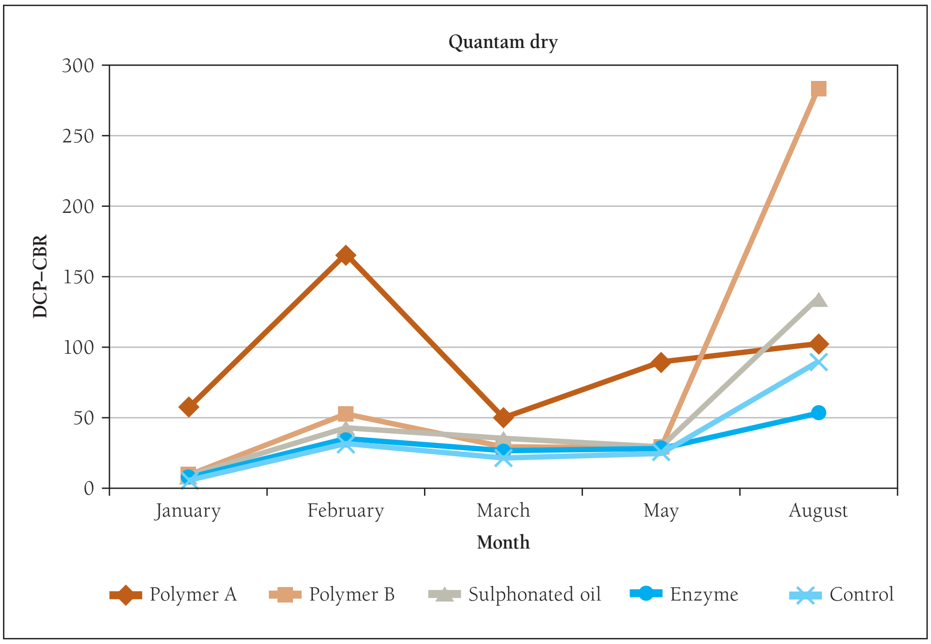

Figure 5 DCP-CBR of the Quantam clayey sand

STRENGTH BEHAVIOUR OVER TIME

Secondly, the soaked and in-situ CBR results for each panel over the test period were compared. This was done to get an indication of the improvement, or deterioration, of the strength of the stabilised material, under wet and dry conditions, over a five-month period. This gave an indication of the time each stabiliser needed to reach its maximum strength.

Figure 5 indicates the strength behaviour of each stabiliser on the Quantam clayey sand material over time for the dry condition, and figure 6 indicates the strength

Table 4 Summary of strength behaviour of stabilised panels versus control panels

Stabiliser	Material	Maximum in-situ strength			Comments on strength	Maximum soaked strength			Comments on strength
		Month	Control DCP–CBR	Stabilised DCP–CBR		Month	Control DCP–CBR	Stabilised DCP–CBR	
Polymer A	Putfontein	March	15	34	Improvement	February	5	17	Improvement
	Daveyton	August	134	88	Reduced	February	4	28	Improvement
	Benoni	August	220	107	Reduced	August	25	29	Improvement
	Quantam	February	36	160	Improvement	February	6	160	Improvement
Polymer B	Putfontein	February	23	39	Improvement	August	5	11	Improvement
	Daveyton	August	134	170	Improvement	August	4	7	Improvement
	Benoni	August	220	120	Reduced	February	7	27	Improvement
	Quantam	August	85	194	Improvement	February	6	7	Improvement
Enzyme	Putfontein	August	73	110	Improvement	August	5	7	Improvement
	Daveyton	August	134	91	Reduced	February	4	4	No change
	Benoni	August	220	96	Reduced	August	25	10	Reduced
	Quantam	August	85	125	Reduced	August	6	23	Improvement
Sulphonated oil	Putfontein	August	73	131	Improvement	February	5	5	No change
	Daveyton	August	134	245	Improvement	August	4	7	Improvement
	Benoni	August	220	245	Improvement	February	7	31	Improvement
	Quantam	August	85	199	Improvement	May	5	13	Improvement

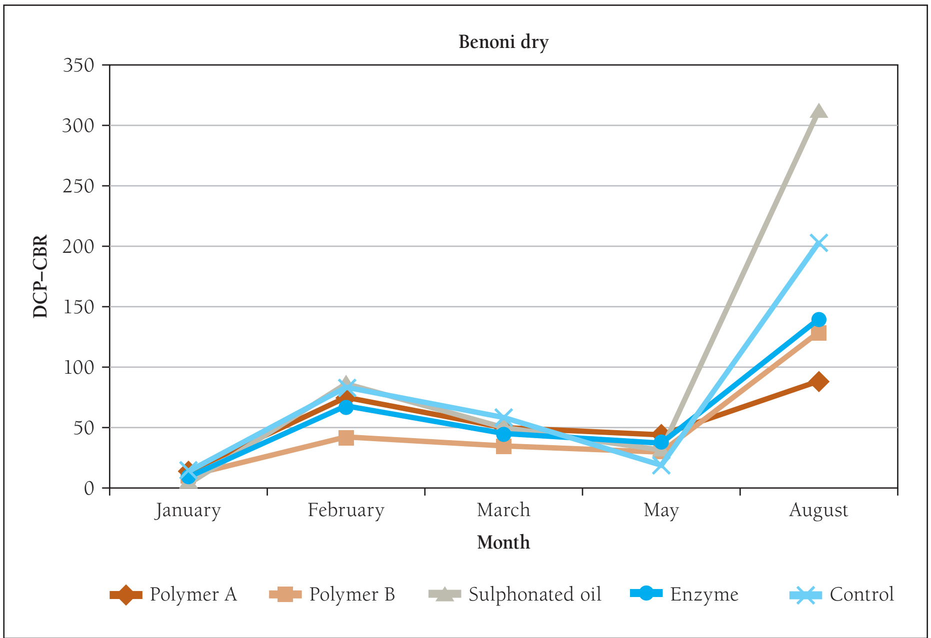

Figure 6 DCP-CBR of the Benoni clay

behaviour on the Benoni clay for the dry condition. A comparison with the control panel is also made.

From the results it was concluded that the polymers reached their maximum strength in February, while the enzyme and sulphonated oil reached their maximum strength in August, after eight months. The panel with the highest strength in January was a panel that did not show any improvement over the whole period of study and showed low CBR values. The Quantam material stabilised with polymer A indicated a very high soaked CBR and this data was concluded to be spurious, the second highest soaked CBR being 108 in March. When stabilised with the enzyme and sulphonated oil, the materials showed an ongoing improvement after February and this may indicate that these stabilisers reach a high strength within a few months but could improve further over an extended period of time. The polymers reached a maximum strength in February and it did not seem as though any further improvement in strength occurred.

The high strengths in February may be ascribed to the fact that the least amount of rain fell in that month, with only 11 mm being measured for that month before testing was done. It is likely that if less rain fell in January the stabilisers may have reached an optimum strength within a month or even less.

However, it can be concluded that the polymers used reached a maximum strength after two months of construction and that the enzyme and sulphonated oil did show an ongoing improvement after two months.

PERFORMANCE OF STABILISED PANELS VERSUS CONTROL PANELS

The maximum in-situ and soaked CBR of each stabilised panel was compared with the in-situ and soaked CBR of the control panel for the same month. Even though the control panel may have had a higher strength in another month, this value was not taken into consideration for the comparison. This was done so that a true comparison could be drawn between the material with and without the stabiliser, as conditions varied significantly between certain months of testing. It was an improvement when the stabilised panel had a CBR more than 10 % greater than the control panel. The comparison was done over the whole period of the study. A summary of the maximum in-situ and soaked CBR of each stabilised panel, compared with the in-situ and soaked CBR of the control panel for the same month, can be seen in table 4.

Polymer A showed an improvement on the Putfontein and Quantam materials, and polymer B showed an improvement on all the materials except the Benoni clay. The improvement in soaked strength on the polymer A stabilised Benoni clay was not significant, and polymer B had a significant improvement in soaked strength

Table 5 Permeability test results (colour code: green – lower, orange – higher)

Material	Units	Product
Putfontein (clay)		
Panel 1	165	Polymer A
Panel 2	300	Polymer B
Panel 3	250	Enzyme
Panel 4	180	Sulphonated oil
Panel 5	265	
Daveyton (sand)		
Panel 6	27	Polymer A
Panel 7	195	Polymer B
Panel 8	100	Enzyme
Panel 9	60	Sulphonated oil
Panel 10	102	
Benoni (clay)		
Panel 11	180	Polymer A
Panel 12	200	Polymer B
Panel 13	150	Enzyme
Panel 14	135	Sulphonated oil
Panel 15	Unable to test panel	
Quantam (clayey sand)		
Panel 16	100	Polymer A
Panel 17	200	Polymer B
Panel 18	175	Enzyme
Panel 19	170	Sulphonated oil
Panel 20	220	

on the Benoni clay. It became evident that the polymer B treated materials did not perform well under wet conditions. The enzyme showed an improvement on the Putfontein and Quantam materials, with a significant increase in soaked strength for the Quantam material. The sulphonated oil showed an improvement on all the materials, with the Benoni clay indicating the only significant increase in soaked strength. This increase in soaked strength for the sulphonated oil stabilised Benoni clay was attributed to the reactive clay found in the material.

It is hypothesised that the weak performance of the stabilisers can be attributed to the fact that the tests were done during the rainy season and that none of the panels had time during the first five months to dry out sufficiently for significant strength improvement to occur after construction. However, this does not mean that all of these stabilisers will work in drier conditions, and it may be that some of the stabilisers performed poorly in practice because they simply do not work with the specific type of material. The good performance of the polymer A treated panels on the soaked strength could be attributed to the fact that these panels received a final application after compaction that sealed the material layer and prevented excessive water from entering the pavement layer. The high in-situ strength of the Benoni clay control panel during February, March and August, in contrast to the other months, is an indication of a water-susceptible clay that has a high strength when the material is dry and low strength when the material is wet. It is clear to see that there was an increase in dry strength for almost all the panels in August during the dry winter months, adding to the fact that the low strengths during the other months may be attributed to wet conditions.

The soaked CBR strength of the Benoni panel stabilised with polymer B in February was much higher than the rest of the soaked CBR results for that panel. This result must be evaluated with care as discrepancies may have entered the testing of the panel. It was decided not to take this result into consideration for the analysis because no explanation could be found for the sudden increase in strength for that month.

PERMEABILITY OF TEST PANELS

The permeability test done with the use of the Marvil permeameter gave a good indication of the permeability of each panel. The results are given in table 5.

The Marvil permeameter is marked in units from 0 to 300 on the measuring tube. The units have no value and serve only as an indication of the level to which the water has dropped in the measuring tube. For each test the water level was measured five minutes after water was poured into the instrument up to the 0 unit on the measuring tube. A green block indicates a lower permeability than the control material and an orange block indicates a higher permeability.

It must be noted that the densities of the panels play a significant role in the permeability of the panels. However, since the Troxler test results were inconclusive on the densities of the panels or the increase and decrease of densities over the test period, the permeability test results are only used to try and conceive why such low-soaked DCP-CBR results were found on certain panels.

The results indicate that the polymer B treated material had a high permeability. This may have caused water to enter the panels stabilised with this product more freely, leading to a higher moisture content during the soaked CBR tests. This could indicate why low CBR strengths were obtained during the soaked DCP tests. Polymer A and the sulphonated oil seemed to decrease the permeability of the soil. Note that the polymer A stabilised panels had a sealing layer after construction and this may have inhibited water infiltration, rather than the density of the material. The Benoni clay's control panel had such a rough surface that it was impossible to test the permeability by using the Marvil permeameter.

CONCLUSIONS

Four materials were used during this study, each with slightly different material characteristics. This study was only undertaken under one climatic condition and the results may only be applicable to this specific climatic condition. During the study the DCP was used with success to determine the wet and dry in-situ CBR of the test panels. A change in the relative compaction during the five-month testing of the panels was noticed, but poor repeatability of the results was found and no reliable conclusions could be drawn on the increase or decrease of relative compaction over time for any particular panel.

The pavement materials treated with the polymers reached a maximum strength after two months of construction and no further improvement was noticed. However, the pavement materials treated with the enzyme and sulphonated oil showed an ongoing improvement in wet and dry strength after two months, indicating that these stabilisers need time to cure before the stabilised material reaches its maximum strength.

Polymer A stabilised panels showed an improvement on all the materials except the Benoni clay. This could be ascribed to the fact that the panels stabilised with Polymer A received an application after compaction that led to a sealed layer effectively keeping out the water. It was determined that the polymer B stabilised panels showed an improvement on all the materials, but did not perform well under wet conditions. The enzyme stabilised panels showed an improvement on the Putfontein and Quantam materials, with a significant increase in soaked strength for the Quantam material. The sulphonated oil stabilised panels showed an improvement on all the materials, with the Benoni clay indicating the only significant increase in soaked strength. The good performance of the sulphonated oil on the Benoni clay was attributed to the fact that the Benoni clay contained a reactive clay mineral that produced a permanent association between the soil stabiliser and the clay particles.

The initial weak performance of the stabilised materials was attributed to the fact that the tests were done during the rainy season and that none of the panels had time to dry out sufficiently for significant irreversible strength improvement to occur. It was also concluded from the final tests done in month eight that the stabilised materials perform better if they have had a few dry months to reach their maximum strength.

The final conclusion reached was that there are soil stabilisers available that do improve the strength behaviour of pavement materials. It is however important to choose the correct stabiliser for the intended purpose. To gain the optimum performance from the chosen stabiliser it is recommended that the stabiliser be applied during the dry season to ensure that the stabilised pavement material reaches its full strength. The test protocol used in this study could be effectively used to evaluate material and stabiliser combinations in the field, so that there is no need to rely on laboratory tests which may not represent field conditions.

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REFERENCES

Department of Transport 1990. Draft TRH20: The structural design, construction and maintenance of unpaved roads. Pretoria: The Department.

Department of Transport 1993. Towards appropriate standards for rural roads: discussion document. RR 92/466/1. Chief Directorate National Roads, South African Roads Board.

Foley, G, Cropley, S and Giummarra, G 1996. Road dust control techniques. Special Report 54. Victoria, Australia: ARRB Transport Research Ltd.

Jones, D and Ventura, D F C 2003. Development of fit-for-purpose certification testing for non-traditional road additives – Phases I – III. Contract Report: CR – 2003/34. Pretoria: CSIR, Transportek.

Visser, A T and Erasmus, F 2005. Practical evaluation of additives used for soil stabilization. *IMIESA*, 30(4).

www.cbrplus.co.za (CON-AID International (Pty) Ltd). Accessed 12 November 2004.

www.PERMA-ZYME11X.com (Perma-Zyme 11X). Accessed 12 November 2004.