

**THE PERFORMANCE AND BEHAVIOUR OF BITUMEN EMULSION TREATED ROAD BASES IN SOUTH AFRICA**

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Emulsion treatment of granular bases is used mostly as a rehabilitation option in South Africa. Emulsion treated bases (ETBs) have been used on an ad hoc basis in South Africa in the past. Considerable work has gone into the mix design of ETBs, but in general, the modelling of ETB pavements lacks performance data. Accelerated testing with the Heavy Vehicle Simulator (HVS) fleet in South Africa has proven to be the ideal way of evaluating and modelling the performance of ETB pavements. Experimental sections and previously constructed ETB sections were tested. The outcome of these tests has contributed significantly towards the increased use of ETBs in South Africa. Research on ETB with natural gravels are also reported on.

**INTRODUCTION**

Small percentages of bitumen emulsion is often used as a form of treatment of road building materials. Emulsion treatment is mostly considered in South Africa in cases where cold mix recycling of cracked cement treated bases are conducted. A large proportion of roads in South Africa has cement treated bases (de Beer et al, 1). Typical problems such as cracking, water intrusion, potholing and height restrictions in urban areas, favour recycling as a viable rehabilitation option (Horak et al, 2). Such an existing base or subbase is milled and treated with small quantities of bitumen emulsion and then relaid as an emulsion treated base (ETB) or subbase. The percentage of emulsion used is normally about one per cent. The addition of an equally low percentage of cement during ETB construction is also increasingly used because of its added early strength gain which assist in bridging the tender stage during curing and thus making ETBs more durable.

Emulsion treatment is, however, not restricted to cold mix recycling only, but is also used with freshly crushed rock and natural gravels. Emulsion treatment is used for a number of reasons. It has obvious construction advantages such as a "lubrication effect" during construction with a resultant lesser compactive effort needed, less compaction water is needed, minimizing segregation and enabling construction of daily sections which can be opened to traffic. Emulsion treatment is also environmentally friendly. It is also considered to be very efficient in limiting the ingress

of water, by being less permeable than normal granular layers and therefore limiting the destructive effect of Moisture Accelerated Distress (MAD) under the action of traffic loading.

Considerable work has been done on the mix design of ETBs (Santucci and Hayashide, 3), but in general, the modelling of ETB pavements lacks performance data needed to verify the design methods used. Long term pavement performance (LTPP) studies are the best way of confirming design methods and analysis procedures. It is however a costly and lengthy analysis (OECD, 4). The HVS system is the ideal tool for doing accelerated testing of such pavements (Freeme et al, 5 and 6) in order to gain valuable information on the performance of ETB's in anticipation of recently commenced LTPP studies (Wright et al, 7) on ETB pavements in South Africa.

The main focus of this paper is on the performance of ETBs under accelerated testing with the Heavy Vehicle Simulator (HVS) system in South Africa. This paper also briefly deals with mix design considerations for the emulsion treatment of natural gravels.

### PERFORMANCE UNDER ACCELERATED TESTING

Accelerated testing with the Heavy Vehicle Simulator (HVS) system (5) and technology have enhanced the understanding of pavement behaviour and modelling in South Africa significantly (5 and 6). The HVS is a mobile accelerated pavement testing rig that tests as-built pavements. Acceleration of testing is achieved through the backwards and forward movement of a dual wheel load over a selected 8 m by 1 m test section. Additional acceleration is achieved by overloading the dual wheel load (up to 200 kN versus the 40 kN standard). Additional to the test rig, sophisticated response measuring equipment were developed to measure deformation and deflection on the road surface and in depth of the pavement, crack movement, moisture content and the artificial inducement of water into the pavement.

Three ETB sections were tested with the HVS. In an evolutionary progression two experimental sections were constructed and tested with the HVS before an as built pavement, rehabilitated with an ETB, was tested with the HVS. These sections tested sequentially with the HVS, are experimental sections constructed on the National Route N3 on the Pietermaritzburg Bypass in Natal (Horak and Viljoen, 8), an experimental section of half depth milled and recycled as an ETB on Main Route 37 at Platteklouf near Cape Town (2) and the rehabilitated section of National Route N2 Section 16 at Kwalaria River near East Londen in the Cape Province (Jordaan et al,9).

The discussion of the abovementioned sections is deliberately in chronological order to illustrate the improvement in performance and standards achieved through applied knowledge gained. In each case, the pavement structure, the HVS test programme which was followed and other aspects specific to the tests done, have had an influence on the performance of the ETBs. Only the most important behaviour data, performance facts and conclusions are reported here.

## N3 Pietermaritzburg Bypass

Four experimental sections of pavement structures were constructed on the National Route N2 on the Pietermaritzburg Bypass. Only 0,9% residual bitumen was used in the ETB as a recycled layer. In Figure 1, the pavement structure tested near Pietermaritzburg (8) is shown with multi-depth-deflectometer (de Beer et al, 10) deflections in depth at two stages of testing. Indicated next to the depth deflection lines, are the effective elastic moduli calculated by means of using linear elastic multi-layered programs (5 and 6). As can be seen from the effective elastic moduli values of the ETB layer, there was clear evidence of non homogeneity in depth once HVS trafficking had commenced. The effective elastic moduli values of the ETB were, however, very low and clearly confirm low densities achieved during construction. In Table I the in situ California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) values determined with the Dynamic Cone Penetrometer (DCP) are given for the particular ETB layer and shown in Figure 1 (de Beer et al, 11) prior to HVS testing. The difference in the top 100 mm and lower 100 mm of the rather thick ETB is evident in these values.

DEPTH	AVERAGE PENETRATION (mm/blow)	CBR (%)	UCS kPa)
0 to 100 mm	3,0	110	800
100 to 200 mm	1,4	250	2100
Full depth	2,2	170	1350

Table I : Dynamic Cone Penetrometer (DCP) results of the ETB

In Figure 2 the progression of the rut measured with a straight edge is shown versus actual load repetitions of a dual wheel load. The summary of the test, with reference to change in wheel load and artificial surface temperature control, is indicated. Most of the deformation originated from the 90 mm recycled asphalt surfacing, during the heating of the section. High dual wheel loads of 100 kN had no significant acceleration effect on the rut progression at normal temperature though.

Limited space does not allow a detailed discussion on the relevant information gained during initial investigations. However, the conclusions after the HVS test were as follows (8) :

- The ETB layer was too thick and had clear indications of non-homogeneous compaction in depth leaving it prone to shear deformation in the top half of the layer. This is a reflection of the typical problems associated with construction of short experimental sections (30 to 40m) such as those tested here.
- The behaviour of the emulsion treated crusher-run base is strongly dependent on the quality and support of the subbase.

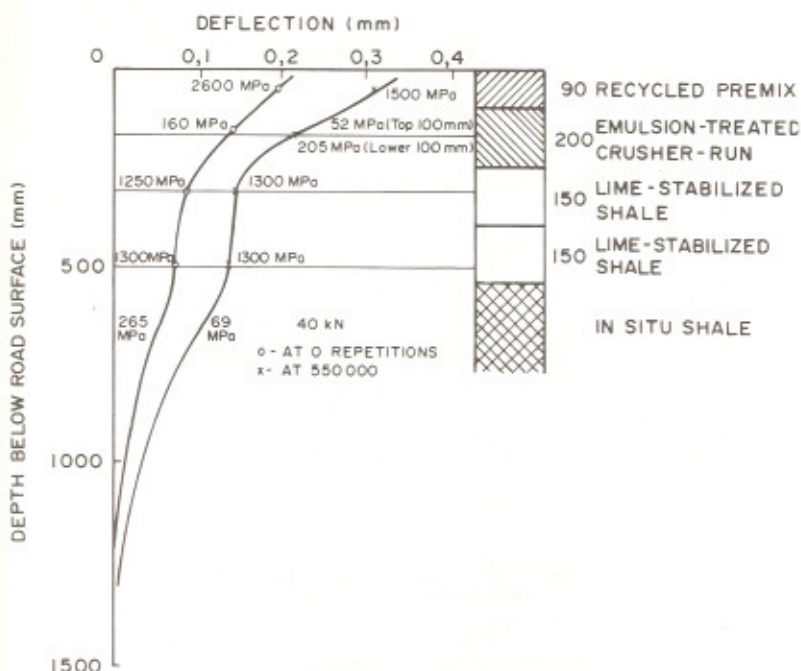


FIGURE 1

*DEPTH DEFLECTIONS AND EFFECTIVE ELASTIC MODULI OF THE ETB AT PIETERMARITZBURG*

- The ETB Dolerite crusher-run exhibited similar behaviour to that of a good quality crushed stone layer (Maree et al, 12) rather than that of a stabilized bitumen layer. Based on in situ values (determined with the DCP) it acted initially like a lightly cemented layer.
- Due to the low percentage of residual bitumen and poor initial density no significant improvement to water resistance was observed. In the light of the above, it was classified as not a true reflection of the behaviour of ETBs.
- The pavement structure tested (see Figure 2) can carry 0,8 to 3 million equivalent 80 kN standard axles (E80s) under wet conditions, but under favourable dry conditions it can carry 3 to 12 million E80s before a 20 mm terminal rut condition is reached.

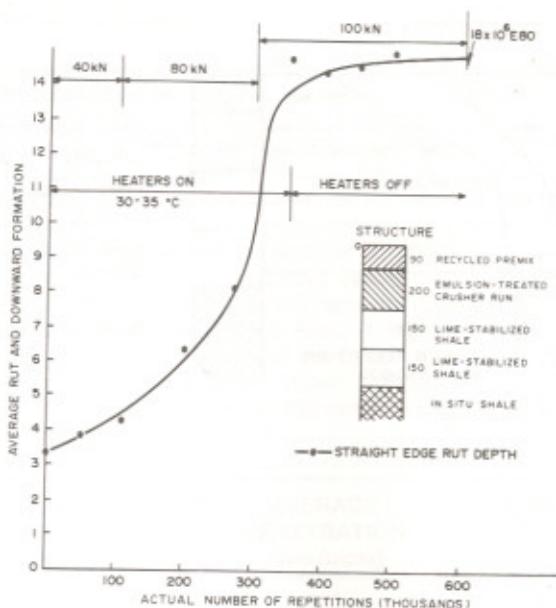


FIGURE 2

AVERAGE STRAIGHT EDGE RUT DEPTH PROGRESSION WITH INCREASE IN REPETITIONS (IN 2 NEAR PIETERMARITZBURG BYPASS)

### Main Route 37 Plattekloof

Main Route 37 at Plattekloof near Cape Town was a badly cracked, strongly cemented pavement that had to be rehabilitated. Due to height restrictions recycling and emulsion treatment of the recycled base were conducted in an innovative manner preserving the residual strength of the pavement. In Figure 3, the half depth milled cement treated base pavement is shown with the rehabilitated milled crusher-run treated with 0,8 per cent nett bitumen (1,35 per cent anionic stable grade 60; per cent emulsion) (2). Indicated in the same figure are the layer strength diagram results of a Dynamic Cone Penetrometer (DCP) survey done before and after the HVS test. These DCP results clearly indicate an "unbalanced" pavement structure initially where there was a substantial difference in CBR (strength) between the residual cement treated subbase and the recycled ETB or the Latterite subbase. This "unbalanced" structure was moulded into a more "balanced" structure towards the end of the HVS test (de Beer et al, 11) with more proportional contribution to strength in depth by all layers. As indicated in Figure 3, the ETB layer showed an increase in CBR value due to the HVS trafficking.

The initial density of the ETB was on average 97% Mod AASHTO which is low for densities required for high quality crushed stone bases in South Africa. Recent specifications using Mod AASHTO specify 102% for such quality crushed stone bases

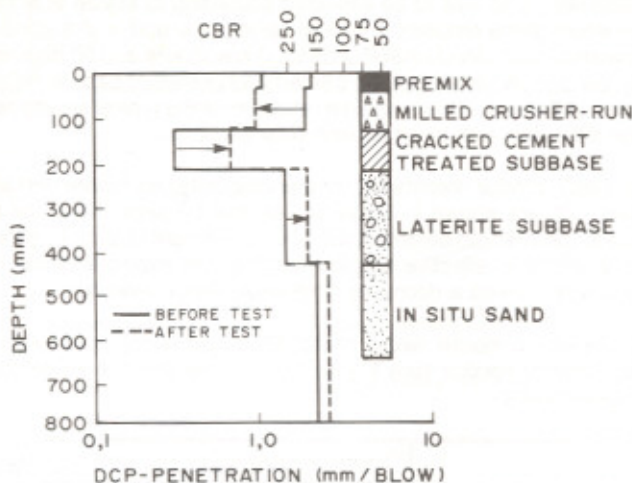


FIGURE 3  
AVERAGE DCP RESULTS BEFORE AND AFTER  
TESTING

(Horak et al, 13). The in situ shear resistance showed an increase in the ETB layer and is illustrated by the increase in penetration resistance reflected in the DCP and CBR values in Figure 3. This is accompanied by an increase in density due to trafficking (2).

Triaxial tests and dynamic repeated-load triaxial tests were done on the treated and untreated milled crusher-run material. The shear parameters,  $C$  (apparent cohesion) and  $\phi$  (angle of internal friction) are shown in Table II together with the values  $K_1$  and  $K_2$  of the resilient modulus,  $M_R = K_1 \sigma^{\theta}$ , where  $\theta$  is the sum of the principal stresses (Maree et al, 14).

SAMPLE	C (kPa)	$\phi$ (degrees)	$K_1$	$K_2$
Treated	17,0	50,2	35,5	0,44
Untreated	27,6	55,4	21,9	0,52

Table II : Triaxial and repeated load triaxial test  
results on milled crusher-run

Both the shear force parameters,  $C$  and  $\phi$ , were lower for the treated material at the low in situ densities. This was to be expected according to Maree et al (12) due to the lubrication effect of the emulsion. Typical values of  $C$  and  $\phi$  of a good quality crushed stone material (102% Mod AASHTO density) are 35 kPa and 50 degrees (14). The insufficiently low density (in situ) of the treated and untreated base is reflected in the low values for  $C$  in Table II. This is again a reflection of the typical results resulting from construction difficulties with short experimental sections.

The effective elastic moduli determined for the various layers before and after the HVS test (de Beer, 15) are shown in Table III. As can be seen there has been a significant change in the strength contributions of the pavement layers. In general the ETB showed an increase in effective elastic moduli at the expense of the cement treated subbase which showed a decrease in effective elastic moduli.

If these effective elastic moduli values of this ETB layer is compared with that of the previous experimental section (see Figure 1), it shows that the Plattekloof ETB section is of a higher quality.

LAYER DESCRIPTION	EFFECTIVE ELASTIC MODULI (MPa)	
	Before Testing	After Testing
ETB	460	1250
Cement treated subbase	3300	1630
Laterite subbase	680	480
In situ sand subgrade	420	350

**Table III : Effective elastic moduli before and after HVS testing (Plattekloof)**

This change in pavement structure balance was also evident in other material state indicators. In Figure 4 the change in permanent deformation is shown for this section with the number of dual wheel load applications. As indicated in Figure 4, the artificial inducement of water into the pavement section (de Beer and Horak, 16) did not have any significant effect on the rate of change of deformation. Measurements with the falling head permeability meter (2) clearly indicated that the ETB was about three times less permeable than the untreated milled crusher-run. As indicated in Figure 4 this ETB pavement can carry in excess of 12 million E80s before it reaches the 20 mm rut criteria.

#### **National Route N2/16 at Kwalera River**

This cracked, cement treated base pavement was rehabilitated in 1980 by means of cold mix recycling of the base and surfacing and incorporating it into an ETB with a cement treated subbase. In this case the ETB was treated with 1 per cent nett bitumen and 1 per cent cement. This HVS test, done on this specific ETB pavement,

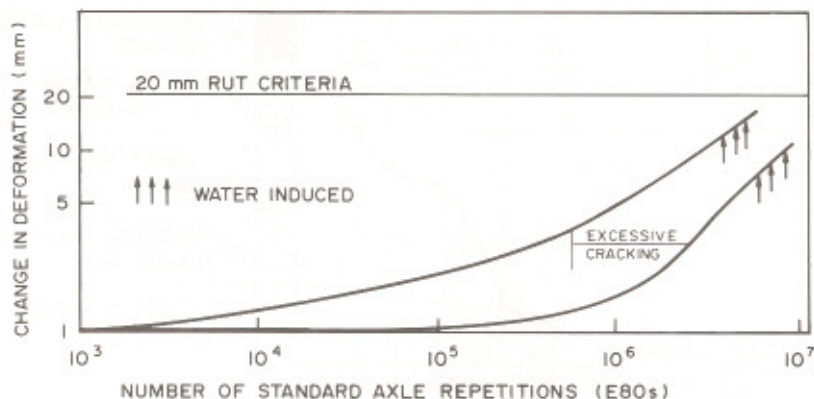


FIGURE 4

*RUT VERSUS STANDARD AXLE REPETITIONS (PLATTEKLOOF)*

was different from the previous two sections discussed, in that it was the first large scale as built ETB pavement plus the fact that cement was added to the ETB.

In Figure 5 the pavement structure is shown with the change in straight edge rut versus actual HVS load repetitions. The summary of the test program is also indicated as far as the dual wheel loading used and moisture condition are concerned. The increase in total number of cracks observed during testing is shown in Figure 6 (9). The crack movement was also measured with the Crack Activity Meter (CAM) to monitor vertical and horizontal crack movement during testing (Viljoen et al, 17). In Figure 7 the CAM results are shown indicating the change in horizontal and vertical relative crack movement as a wheel load moves over the crack. The change in CAM measured activity is closely related to block size and pavement structure response (Viljoen et al, 17).

The state of the pavement structure changed considerably during the HVS testing. A detailed analysis of the in depth deflections measured with the multi-depth deflectometer (MDD) (9) revealed that the selected layer was the "weak" link from where most of the deflection and permanent deformation originated. Initially, the base and subbase had prevented the formation of serious permanent deformation (below 10 mm rut) within the pavement. However, during trafficking at a dual wheel load of 100 kN the base reached the end of its fatigue life and cracked into small blocks, becoming an effective granular layer. These cracks reflected through to the surface, resulting in an increase in the number of cracks appearing on the surface. Continued trafficking caused the selected layer to compact. This coincided with the increase in cracking of the base and the increase in permanent deformation measured as rutting on the surface.



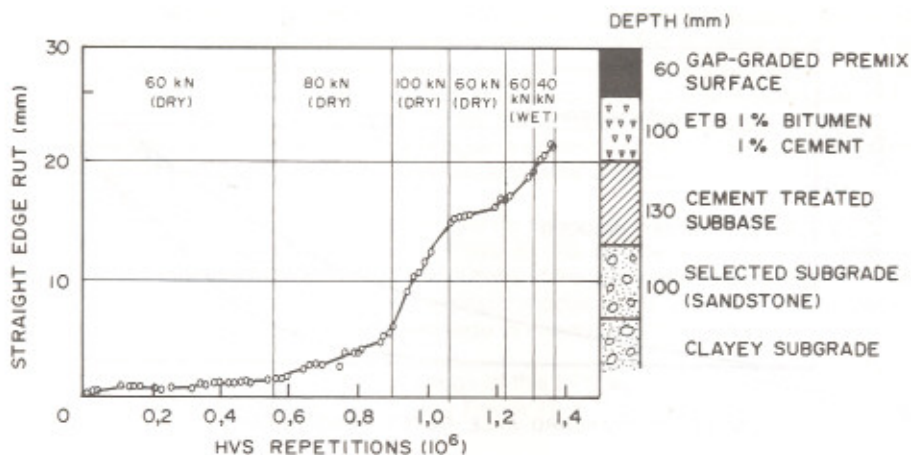


FIGURE 5

*N2: KWELERA: AVERAGE DEFORMATION OF THE ROAD SURFACE DURING HVS TESTING*

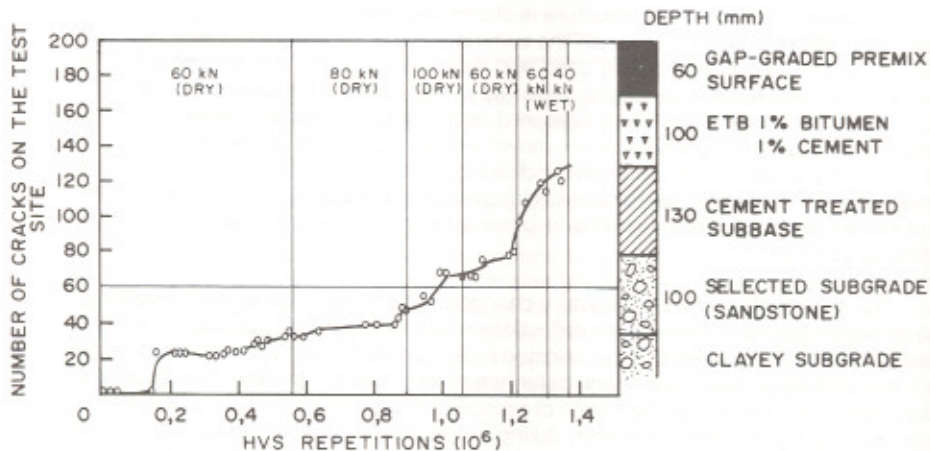


FIGURE 6

*N2 KWELERA: TOTAL NUMBER OF CRACKS VISIBLE ON THE ROAD SURFACE DURING HVS TESTING*

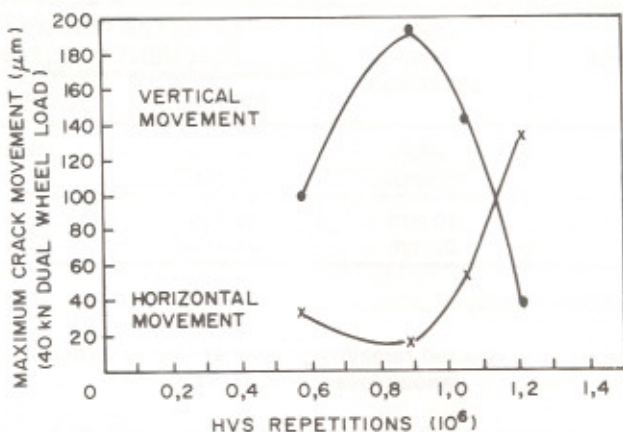


FIGURE 7

*N2 KWELERA : CRACK MOVEMENT DURING  
HVS TESTING*

The wheel loads applied to the pavement were converted to equivalent 80 kN axle loads (E80s) by using an equivalency factor ( $F_n$ ), where

$$F_n = (P/80)^d$$

where

- |       |   |  |
|-------|---|--|
| $F_n$ | = | equivalency factor for load P  |
| P     | = | axle load in kN  |
| d     | = | damage coefficient, which is dependent on the pavement type and material state |

The damage coefficient ( $d$ ) is similar to the "n" value as established during the AASHO road test (Hveem and Sherman, 18). However, HVS testing and other accelerated testing (4) have shown this value of  $d$  to vary depending on the pavement type, material state, loading history, etc. and it is not a fixed value of 4,2 as the n-value was initially determined.

The damage factors calculated, showed that  $d$  had started with a value as high as 7,2 and had gradually decreased to 6 until trafficking with the 100 kN dual wheel load (See Figure 5). Hereafter, it changed to a value of 2,7. From this change in  $d$ -values, it is clear that the pavement had experienced a change in state of behaviour.

The measurements of cracking and deformation (rut depth) were used to statistically calculate the expected life of the pavement to a certain level of cracking or rut depth. The results are as shown in Table IV below.

DISTRESS	LEVEL OF DISTRESS	EXPECTED REMAINING PAVEMENT LIFE (E80s)	
		AVERAGE	EXPECTED *
Cracking (visible)	Initial	2,9x10 <sup>6</sup>	1,9x10 <sup>6</sup>
	Increase	30,7x10 <sup>6</sup>	28,4x10 <sup>6</sup>
Deformation (rut depth)	10 mm	30,8x10 <sup>6</sup>	29,0x10 <sup>6</sup>
	20 mm	31,4x10 <sup>6</sup>	30,1x10 <sup>6</sup>

\* 95% Probability

**Table IV : Expected remaining pavement life in terms of various levels of distress**

This pavement tested has shown that it can carry up to 30 million E80s under normal dry conditions. The addition of one per cent cement and one per cent residual bitumen proved to be effective and resulted in a durable layer capable of withstanding relatively high deflections. The treated layers performed extremely well under these conditions and showed a fatigue life (life before cracking) of longer than that of similar layers normally treated with cement.

The effective elastic modulus of the ETB layer started off at a value of 500 MPa and higher. When the ETB reached the equivalent granular state towards the end of the HVS test this effective elastic value dropped to as low as 200 MPa. These values clearly indicate that initially, the ETB behaved very much like a cement treated base but with improved resistance to cracking. It did however not perform as well as a bitumen base but rather like a material that performed better than a cement treated layer.

#### RECENT RESEARCH : NATURAL GRAVEL ETB

One of the significant differences between the design of ETB material and that of asphaltic mixes is the aspect of curing of the material to simulate the increase in strength with time experienced in the field. As stated earlier, ETB design methods used in South Africa (3) have lacked in an understanding of the relevant engineering parameters of the materials and performance data needed to verify such design methods. Different materials from those generally used in the development of the existing design methods, are also often used in South Africa. The treatment of natural gravels with emulsion offers the possibility of improvement and better utilization of such materials in pavement construction.

In 1988 the Southern African Bitumen and Tar Association (SABITA) commissioned a research project to investigate the above. The design philosophy derived from this work included the following procedures :

- the preparation of laboratory mixes;
- the compaction of laboratory mixes;
- the curing of the samples, and

- the testing of the samples to determine optimum binder content and engineering parameters.

### Laboratory Procedure to Predict Field Parameters

It is not the intent of this paper to report on this new proposed laboratory procedure in detail, but rather to highlight the essential laboratory preparation including factors such as the determination of the optimal fluid content prior to mixing in of the emulsion, and descriptions of a mixing procedure and a pre-compaction curing procedure (aeration). Both the standard Marshall hammer and the modified Marshall hammer (Hugo, 20) were used in this study of the compaction of laboratory mixes. Due to the nature of the material, very little difference was observed in using the modified Marshall hammer and the standard Marshall hammer. It is recommended to apply 30 blows on each side of the sample.

An extensive investigation into curing methods was undertaken. Based on the laboratory study and a small scale field experiment, a twenty hour cure at 40 °C was suggested to predict strength.

The following mechanical tests were conducted during the laboratory investigation:

- the diametral resilient modulus;
- the indirect tensile strength, and
- Marshall stability and flow.

The first two methods were found to give the best results in terms of the prediction of optimum binder content. In addition to the above, an investigation into water exposure is also recommended if the material is to be used in a wet area. Two methods, the Vacuum and Capillary methods were evaluated in the laboratory. The Capillary method was found to simulate field conditions better and is therefore recommended.

### Field Correlation with Laboratory Design

The above procedure was used in the design of five trial sections located in the Orange Free State Province of South Africa. The base was constructed by emulsion stabilisation of a decomposed dolerite which in its natural form, would be inadequate as a base material. The existing subbase was ripped, 2 per cent cement mixed in and recompacted. Five test sections were constructed with the emulsion content ranging from one to five per cent at one per cent intervals. In this case, two per cent lime was added to the base.

Table V shows the test results for indirect tensile strength and resilient modulus for laboratory manufactured samples for which the 20 hour at 40°C curing procedure was used as well as for cores taken after one month of field curing. Figure 8 shows that, although the laboratory values of resilient modulus are generally lower than the field values, there is a very good correlation between the data sets with  $R^2$  values generally around 0,95. This trend was also observed in the indirect tensile strength tests. The design method successfully predicted the optimum emulsion content to be used.

This illustrates that this procedure can be used effectively to design ETB layers. The laboratory testing conducted can also be used to predict the engineering properties to be expected in the field.

EMULSION CONTENT	ITS (kPa)		RESILIENT MODULUS (MPa)	
	LAB	FIELD	LAB	FIELD
1	70	345	406	769
2	83	306	442	845
3	114	343	494	834
4	108	312	487	778
5	92	228	420	549

Table V : Engineering Properties of ETB Material

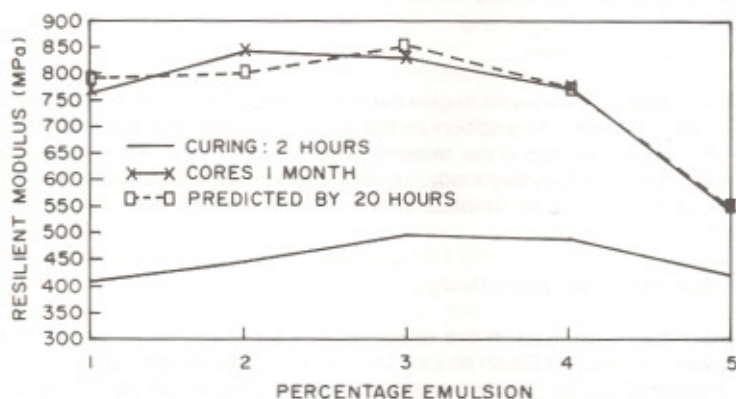


FIGURE 8

RESILIENT MODULUS: CORRELATION BETWEEN 1 MONTH CORES AND LAB-SAMPLES

### CONCLUSIONS

Emulsion treatment of granular bases are primarily being used as a rehabilitation option for cracked cement treated bases in South Africa.

In general low percentages of residual bitumen are used (on average 1 per cent) with less compaction effort and resistance to water intrusion when properly constructed to new higher density specifications.

The addition of low percentages of cement or lime to the ETB has additional benefits in terms of strength and durability. The performance of such ETB pavements during accelerated testing with the HVS warrants the additional cement.

Fatigue relationships are still not available but initial HVS results have proved that the cracking behaviour of ETB pavements is better than that of cement treated bases but not as good as that of asphalt bases. ETBs are however highly flexible layers which can accommodate high deflections even in a cracked state without loss of integrity.

A newly developed mix design procedure was developed for ETB layers in South Africa. This procedure was tested with emulsion treatment of a natural gravel and has proved able to predict cured strength accurately. It has also proved to be successful in determining the optimum emulsion content to be used.

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### KEYWORDS

Analysis, Axle loadings, Bearing capacity, Bitumen, Construction, Crushed rock, Deformation, Density, Elastic Properties, Gravel, Mix design, Recycling, Rehabilitation, Shear strength, Triaxial tests.