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The Control of Reflection Cracking with the use of a Geotextile. A Ten Year Case History

Controle des lezardes causées par reflection en utilisant une natte géotextile—Un historique de dix ans

During 1973 preventative maintenance was carried out on a major freeway section that had manifested severe cracking of the asphalt due to reflection from the underlying cement stabilized base course layer. A levelling course of 20 mm was laid after placing sand 300 mm wide and 5 mm thick as bondbreaking material at every crack, the average crack spacing being 2,5 m. A geotextile mat was then placed and overlaid with 50 mm asphalt. The pavement has been monitored since the completion of the work and after 8 years is still giving excellent service. However, the development of reflection cracks now appears to be taking place at an increasing rate. An inspection of the cracks revealed that they had probably been caused by one or more of several factors. From the evaluation it was clear that the geotextile asphalt system was capable of dealing with plain strain conditions. However, more complex conditions resulting from degradation of the structural system apparently causes vertical movement which cannot be accommodated by the system. Future maintenance will have to cater for this condition.

Pendant 1973, un entretien préventif a été fait sur une majeure partie de l'autoroute, là où il s'était manifesté des lézardes importantes dans l'asphalte, causées par la réflection de la couche sous-jacente de base, stabilisée avec du ciment. Une assise de nivellement de 15 mm a été posée apr`es avoir placé par dessus chaque lézarde, en tant que matériau non-agglutinant, 300 mm de sable de 5 mm d'épaisseur, la moyenne d'espacement entre les lézardes étant de 2,5 m. Une natte géo-textile a alors été placée puis recouverte de 50 mm d'asphalte. Ce pavage a été surveillé depuis installation, et après 7 ans est en état excellent. Cependant le dévelopement des lézardes due à la reflection semble être en accélération. Après inspection, il semblerait que les lézardes seraient causées par un ou plusieurs facteurs divers. A l'analyse, il était clairement évident que le système géo-textile asphalteux était parfaitement capable de tenir le coup aux déformations ordinaires. Les conditions plus complexes, découlant de la dégradation structurelle, causait de toute évidence un mouvement vertical que le système ne savait pas accomoder. Les entretiens futurs devront prendre cette condition en considération.

PILOT STUDY

During 1971 it was decided to carry out preventative maintenance on a section of a major freeway near Johannesburg that had manifested severe cracking of the asphalt due to reflection from the underlying cement stabilised base course. The climate of this region is mild with average temperature ranging between 4°C and 26°C. Average annual summer rainfall is 720 mm. Attempts at sealing of these cracks by means of a rubberised emulsion had not been very successfuly, mainly due to the high stress on the joint material and the rapid deterioration of such material as a result of exposure to the environment. Preventative maintenance had to be done since it was feared that possible pumping action could lead to rapid deterioration and early failure of the pavement.

The pavement structure consisted of the following:

Cont. graded asphaltic concrete surfacing (AC)	25 mm
Cement stabilised Crushed Stone Base Course	150 mm
Cement Stabilised natural gravel sub-base	150 mm
Selected Subgrade	150 mm
Insitu Subgrade-Residual decomposed granite	

Small experimental sections were initially constructed in November 1972, using Structofors, a bitumen impregnated polyester woven fibre with a grid pattern of approximately 15 mm square. From these initial investigations it became apparent that a minimum surfacing of 50 mm was required on top of the geotextile, since thinner layers suffered from stresses set up in the geotextile fibre causing the overlay to crack and crumble. Nevertheless, the work showed great promise and it was decided to carry out a pilot study before executing any major construction work. Accordingly, the following steps were taken:

1 In January 1973 a test section of approximately 50 m in length was built on a portion of the freeway requiring maintenance.

2 The use of the geotextile as reinforcing material was investigated by constructing a control section alongside without any reinforcing. In addition, steps were taken to investigate the effect of a bondbreaker at the cracks since it had been determined that this was a necessary feature of the system.

3 Subsequent to the carrying out of the field experiment a model test was also conducted in the laboratory in order to establish limits for the application of the method. These laboratory tests were supplemented by using the Heavy Vehicle Simulator of the National Institute for Roads and Transport Research in Pretoria. The pilot study was found to be very successful and full reports have been published elsewhere. (1) (2) (3). For the sake of completeness a brief review of the results will be discussed.

Field Experiment (1)

4 In the case of the field experiment it was found that the geotextile was successful in preventing reflection cracking related to the effect of environmental forces. After 15 months in service the sections with Structofors had between 30 and 45% of the original cracks reflected through, whereas the unreinforced asphalt mixture had 60% reflection cracks.

The lime bondbreaker had not functioned well primarily because it was too thin. The effect of traffic had also been investigated by means of the HVS and the equivalent of more than 4 x 10^6 - 80 kN axle loads had been applied. It was found that some of the reflected cracks tended to close up due to the kneading action. It must, however, be conceded that these axle loads had been applied over a relatively short period of time with the result that long term the interaction between load application and environmental forces was not present. This is a fact that will be considered again when reviewing the present situation.

Laboratory Experiment (2)

5 The laboratory study was carried out by constructing a gap graded asphalt mixture (AC) on two adjacent concrete slabs lying on rollers supported by a steel frame, thus forming an artificial crack between the two. One slab was fixed to the steel frame and horizontal movement at the crack was affected by a weight applied to a cable over a pulley on the other side. An attempt was also made to simulate relative vertical movement at the joint using a cam under one of the slabs. The asphalt was placed in two layers, 25 mm as levelling course and a 75 mm overlay.

The following overlays were evaluated in this experiment:

(a) Reinforced AC overlay without bondbreaking.

(b) Reinforced AC overlay with a 500 mm wide bondbreaker 5 mm thick straddling the crack.

(c) AC overlay only.

(d) Unreinforced AC overlay with sand bondbreakers as before.

Results of Laboratory Experiment

6 Figure 1 indicates some results of this experiment. At a crack width of 2 mm it can be seen that for the AC overlay alone the strain at the joint was 3,5 times that of the overlay consisting of reinforced AC with bondbreaking. Also the strain at the crack in the reinforced overlay without bondbreaking was 2,8 times lower than that in the unreinforced overlay. Bondbreaking alone reduced tensile strains by approximately 25%. Movement at the joint was distributed over a much larger area with the reinforcing and bondbreaker.

During this experiment it was also noted that with reinforced overlays the crack could be opened considerably more before cracks appeared on the pavement surface as indicated in the following table.

Table 1 Strain Behaviour of Overlay Systems

Overlay Type	Maximum crack width before reflection (mm)
AC	3
AC with bondbreaking	4
Reinforced AC without bondbreaking	9
Reinforced AC with bondbreaking	18

7 From the results (2) it was found that the strain immediately prior to rupturing of the overlay was in excess of 1,5%. The rate of deformation had not been equal for the four tests but varied between 2,0 mm/hr and 5x10^{-3} mm/hr.

8 Despite this wide range the maximum strain at the surface of the AC overlay did not vary much.

9 When the crack was opened the stress concentration tended to rupture the overlying asphalt. However, the crack only proceeded a short distance before it was checked by the geotextile-sand system and reflected parallel to the surface. As the strain was increased micro cracks formed. Ultimately reflection occurred some distance from the crack. Fig. 2 shows one such test in progress.

10 A repetitive relative vertical movement of 1 mm applied to the system at 1 Hz indicated that the unreinforced overlay could take 27 000 applications whereas the reinforced system with bondbreaking was capable of withstanding 3 x 10^6 repetitions. Of course these results are only relative since the method of application of the vertical movement did not simulate a wheel load moving over a crack, but since the test was strain related, it gave confidence in the reinforced system. The experiment thus indicated that load and temperature strains in the overlay could be catered for using reinforced AC plus a bondbreaker over the crack.

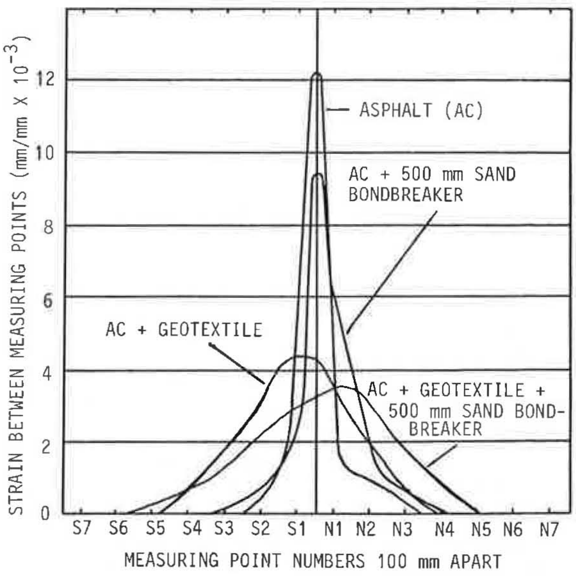

FIG. 1: STRAIN PATTERN FOR DIFFERENT TYPES OF OVERLAYS AT CRACK OPENING OF 2 mm

FULL SCALE CONSTRUCTION

In the light of the success of the preliminary study, it was decided to award a contract for the construction of 80 000 m² of 50 mm geotextile reinforced asphalt with 300 mm of bondbreaking material at every crack, the average crack spacing being 2,5 m. The pavement has been monitored since the completion of the work and after 8 years it is still giving excellent service. However, the reflection cracking has steadily been increasing and it now appears to be taking place at an increasing rate. The subsequent discussion relates to the details of the construction and the subsequent behaviour of the pavement structure.

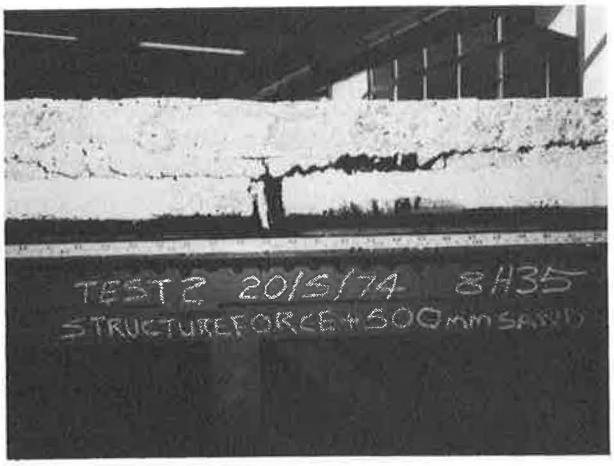

Fig. 2 Test with Structofors and Sand Bondbreaker in Progress

The method of construction used in practice was as follows:

(a) Cracks were cleaned properly using compressed air prior to the application of 0,35 l/m^2 of 45% cationic bitumen emulsion.

(b) Sand was spread over the cracks using a specially designed manually operated sand distributor. The thickness of the sand was 5 mm and the width 300 mm. Sand used was a fine mine sand, crushed in the gold mining process, the grading of which can be seen in Table 2. This sand spreading operation was done immediately in front of the paver in order to ensure as little disturbance of the sand by trucks moving over it, as possible.

Table 2 Grading of Sand

Sieve size (mm)	% Passing
1,18	100
0,600	98
0,300	68
0,150	30
0,075	15

(c) After the sand had been placed, a levelling course of 20 mm thick AC was paved followed by another tack coat. Marshall and other properties of the AC mix used for the levelling course are given in Table 3.

(d) The geotextile reinforcement used was manufactured from a polyester fibre impregnated with bitumen. It was a woven 15 mm mesh and supplied in rolls 1,6 m wide and 150 m long. Overlaps of 150 mm at longitudinal and 300 mm at transverse joints were used. The geotextile was unrolled on the tack coat and nailed down to the surface at approximately 20 m intervals.

(e) A 50 mm gap graded asphaltic concrete layer with precoated chips rolled into the surface was paved over it. The properties of the AC wearing course are given in Table 3.

Table 3: Properties of Asphaltic Concrete Mixes

	Levelling coarse	Final coarse
Bitumen content	7,0	6,5
Marshall flow	2,2	2,3
Marshall stability	5,62	6,03
Voids in mix %	6,4	7,6
Binder type	60/70 Pen	60/70 Pen
Grading:		
Sieve size (mm)	% passing	% passing
26,5	100	100
19,0	100	88,9
9,5	98,9	64,9
6,35	74,0	64,1
4,76	68,1	62,8
2,36	63,2	58,4
1,00	60,8	54,3
0,500	57,4	50,8
0,295	38,6	29,9
0,150	19,8	15,4
0,075	8,5	7,4

Construction Problems

The following problems were encountered during construction:

(a) It was found that the paver tended to push the sand somewhat in the direction of paving. For this reason the sand width was reduced from the originally intended 450 mm to 300 mm and it was spread slightly eccentric. Cores drilled out afterwards indicated bondbreaking to a width of 450 mm symmetrical over the crack. At least 5 mm of sand was necessary to ensure proper initial bondbreaking.

(b) Trucks moving over the sand did not pose any greater problems as far as disturbing the sand is concerned. However, windy conditions did pose a problem and could bring construction to a halt.

(c) Provided the geotextile was nailed down properly no problems were encountered with trucks moving over it.

(d) In constructing the final layer on top of the geotextile it was very important that no horizontal movement took place between the geotextile and the AC overlay during compaction, since this caused the asphalt to disintegrate.

Such movement would cause shearing off of the overlay just above the geotextile resulting in potential slip between the two layers and also a loss in the effectiveness of the reinforcing layer. Care also had to be taken with the design of the AC to ensure that the stone content was high enough to prevent slippage on the underlying levelling course.

PERFORMANCE OF THE OVERLAY

The overlay was completed in 1974 and has since carried a traffic load of around 2 million equivalent 80 kN axle loads. Very little deterioration in riding quality has been experienced and reflection cracking has also been slow in developing, reaching about 30% by 1979. However, since 1979 cracks have been developing at an increasing rate reaching 60% in 1982. This trend is indicated in Fig. 3 showing the length of cracks which have apparently been reflected as a percentage of the original cracks. Fig. 4 shows a general view of the site during construction of the test section. Fig. 5 shows to what extent the overlay has cracked to date: The cracks have been demarcated with liquid lime.

Evaluation of Cracks

The nature and effect of cracks was considered by carrying out a survey and coring through cracks. The following was found:

1 In general the crack pattern was strongly related to the underlying cracked CTB. (Compare figures 4 and 5).

2 Two types could be distinguised, viz.

Type 1: conventional true vertical reflection cracks extending from the top down into the CTB, and

Type 2: randomly spaced, short discontinuous cracks orientated similarly to *Type 1*.

3 6% of cracks were *Type 1* and 94% *Type 2*.

4 Some cracks were found to extend only through the overlay and the underlying CTB being absent inbetween. Apparently these cracks had been deflected horizontally. Clear proof of such deflection was found.

5 The longitudinal cracks had largely reflected through whereas the transverse cracks had not. Less cracks had also reflected through the areas with low traffic volumes eg. zone between off-ramp and slow lane.

6 Whereas the cracks were formerly concentrated in a section of the road they were now spread over 90% of the road length.

7 Little or no evidence of pumping was found.

8 Some evidence of debonding of the overlay was found.

The geotextile was very effective in preventing reflection cracks of *Type 1* and the behaviour of the geotextile system was very similar to that predicted by the laboratory experiment. Furthermore, the fact that the longitudinal cracks have largely reflected through is probably due to the fact that the pavement structure is not contained laterally. The smaller geotextile overlap that was used for the longitudinal joints could also have been a contributing factor. *Type 2* joints could be related to reflection but could also have been caused by fatigue of the asphalt either in plain strain or as a result of the structural behaviour of the system under traffic loads. The limited evidence of debonding is gratifying and lends support for the use of the sand as part of the system.

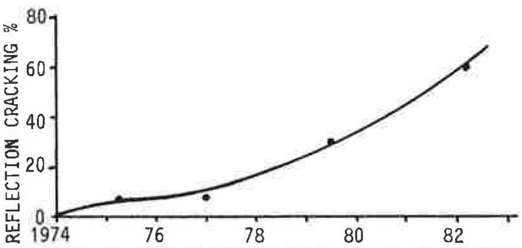

FIG. 3: REFLECTION RELATED TO AGE IN CALENDER YEARS

Fig. 4 General View of Site during Construction of Test Section

Fig. 5 Cracks demarcated with Lime during a Survey February 1982

Evaluation of Deflections

Deflections were measured with a modified Benkelman beam which had the capability of also measuring relative vertical movements under a moving 80 kN axle load at a crack. Deflections measured prior to overlaying were in the order of 0,17 mm with very little relative movement at the reflected cracks. The deflections have increased by about 30% since 1973 and the relative vertical movement under a moving 80 kN axle load at the *Type 1* cracks is now of the order of 0,22 mm. These readings are summarised in Table 4.

Table 4 Deflections under 80 kN Axle Load

	Mean (mm)	Standard Deviation
Prior to overlaying (1973)	0,17 mm	0,10
After overlaying and 8 years service (1981):		
Between cracks	0,21	0,09
At *Type 1* cracks	0,27	0,16
Relative vertical movement *Type 1*	0,22	0,14

The information obtained from deflections, as shown in Table 4, indicates that not only has the deflection increased, despite the overlay of 50 mm but scatter has also increased, especially at the cracks.

Considering the stiffness of the cement stabilised base layer, the pavement can almost be classified as a rigid pavement. Applying measured deflections to a theoretical model, pavement characteristics were calculated by back analysis. The results are shown in Table 5.

Table 5 Theoretical Materials Properties as Calculated from Deflection Measurements and Original Slab Stiffness

Stage	Slab Stiffness (GPa)	Subgrade Stiffness (MPa/m)
Before Overlay (1973)	22*	880
After Overlay and 8 years of use	12	750

*Material stiffness as determined by laboratory testing just after construction.

These results indicate a decrease in stiffness of both the stabilised base layer as well as the subgrade. This seems to point to degradation of the base and the subgrade over the past 8 years and thus a general decrease in structural capacity. The poor condition of some CTB cores as well as the reduction in tensile strength of about 30% as found by limited indirect tests gave support to the conclusion.

Deflections have so far been related to the structural performance of the stabilised base. Another important aspect that also needs consideration, is the performance of the gap graded asphaltic concrete overlay. Cores were analysed and it was found that the physical properties of the asphalt had changed due to traffic and environmental influences. In particular the permeability and density were affected. This in turn affected the stiffness. The capability of the mix to sustain deformation has thus deteriorated somewhat which could have caused the greater incidence of cracking. Results are shown in Figures 6 and 7 and Table 6.

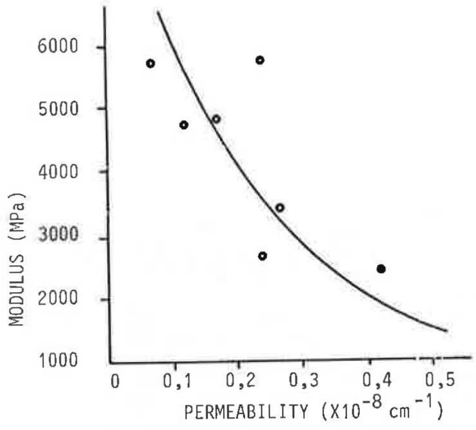

FIG. 6 : STIFFNESS MODULUS VS. PERMEABILITY

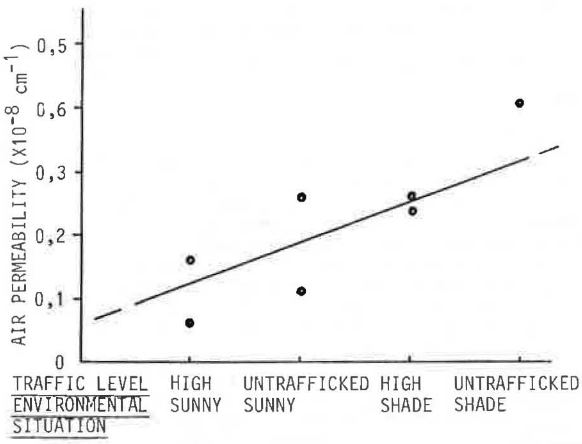

FIG. 7 : INFLUENCE OF THE ENVIRONMENT AND TRAFFIC ON PERMEABILITY

Table 6 Properties of the Asphaltic Overlay

	When constructed (1973)	1981
Stability (kN)	6,0	-
Flow (mm)	2,3	-
Lab. voids (%)	7,6	-
Binder (%)	6,5	-
Air permeability (x10-8/cm)	1,12	0,17
Mix stiffness (MPa)	3600	5200
Road voids (%)	8,2	4,0

Analytical Evaluation

In the light of the foregoing a finite element analysis was carried out to determine what effect these developments would have. Indications are that the max. tensile stresses in the asphalt have been increased by 50% whilst the tensile stress in the CTB has been reduced by 30%. In the light of the degradation of the CTB this is not expected to alter the stress ratio. However, an overall reduction in the fatigue life is to be expected. In fact, the increase in stress level in the asphalt together with the increase in stiffness is likely to cause a decrease in fatigue life of almost one order of magnitude. The deflection results lend support to this argument particularly the increase in relative vertical movement between adjacent slabs. If it is accepted that the structure is basically a rigid pavement with an overlay, an analysis using nomographs developed by Mc Cullough et al (4) predicts a 50% failure of the pavement.

CONCLUSIONS

1 The geotextile reinforced asphalt overlay system has successfully served its prime function to date viz. preventing ingress of water into the pavement structure and consequential damage. It therefore serves as an important tool in the pavement management system. It is, however, clear that the system is not capable of increasing the structural capacity of the pavement since it can only absorb a limited amount of differential vertical movement.

2 It appears as if the structural integrity of the pavement has now reached a critical situation. However, if the life of the overlay can be extended and the asphalt softened by the application of a rejuvenator it may be possible to control the degradation of the CTB to the point where it will function as a conventional crushed stone base.

3 A stabilised pavement system can be treated as a rigid pavement for design purposes but it is important to consider vertical movement of the cracks during the design process. In order to minimise relative vertical movement, the stabilised base should not be too stiff so as to ensure structural cracking in the form of random rather than well defined transverse cracks and the subbase should be of good quality to avoid weathering of the subbase and thus movement of fines and subsequently loss of support of the CTB.

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