Implications of Light Bituminous Surface Treatments on Gravel Roads

A.T. VISSER, J.H. MAREE, AND G.P. MARAIS

Large portions of road networks in many countries consist of gravel or earth roads, which have many undesirable characteristics. They can be dusty in the dry season, slippery and muddy in the wet season, and often develop potholes. It is therefore necessary to find a method of upgrading their serviceability that will not require an extensive capital outlay. The use of dust palliatives and surface seals on gravel roads was investigated. The dust palliatives were tested in a pilot study and found to have a limited life span of some three years. After the first year, roads treated with dust palliatives begin to deteriorate rapidly even with a daily traffic volume of only approximately 90 vehicles and regular maintenance had to be carried out. The Maintenance and Design System program was used to carry out an economic evaluation. Because of such poor performance and the construction cost, this type of treatment is not an economically sound solution. A bituminous surface seal has been used extensively in South Africa on gravel roads or light pavement structures. Roads treated in this way have generally performed satisfactorily. Tests with a heavy vehicle simulator have confirmed this observation. Under dry test conditions, some light pavement structures even carried more than a million equivalent 80-kN axle loads. However, the ingress of moisture through a cracked surfacing resulted in dramatic disintegration. Therefore, timely resealing is important since it prevents the structure from becoming soaked in the wet season. For construction, maintenance, and road user cost combinations commonly found in South Africa, the placement of a surface seal was found to be economically justified at traffic volumes of some 200 vehicles/day. However, sealing is only economically practical if funds can be made available as soon as resealing becomes necessary; otherwise, total disintegration could occur. In such cases it is better to keep the gravel surface.

In many countries, large portions of the road network consist of gravel and earth roads. South Africa has an extensive primary and secondary rural road network of paved roads (46 000 km) but a considerably longer network of unpaved roads (137 000 km). These unpaved roads have certain inherent problems: Earth tracks may become impassable during the rainy season, gravel wearing courses are abraded by traffic and the weather, dust clouds develop in dry conditions, frequent bladings by motor-graders are required to restore the riding quality, and regular regraveling depletes natural resources. These problems are solved by paved roads, but spiraling road construction costs have led to a search for special measures that would overcome some of the problems of gravel roads at a fraction of the cost of paved roads. Examples of such solutions are the application of dust palliatives to gravel roads and bituminous surface treatments on gravel wearing courses, sometimes with the addition of a substantial base layer. These low-cost techniques are intended for use on the tertiary network and are not necessarily applicable to primary and secondary roads.

The aim of this paper is to review briefly the South African experience gained in and the performance data obtained on the use of light bituminous surface treatments on substandard pavement materials, normally those used for gravel roads. The climate in South Africa ranges from wet along the eastern coastal regions to arid in the western parts of the country. The climatic regions and the geographic areas referred to in the text are shown in Figure 1. In addition to the performance data gathered under actual traffic loading, two substandard pavement structures were evaluated with a heavy vehicle simulator (HVS). Finally, the Maintenance and Design System (MDS) program is used for a broad economic analysis of the feasibility of using light bituminous surface treatments, and the cost implications in terms of road maintenance costs and road user costs are also given.

EXPERIENCE WITH LIGHT BITUMINOUS SURFACE TREATMENTS

Dust Palliatives

Dust palliatives are chemical or bituminous agents that are mixed into the upper part of a gravel surfacing or sprayed onto the surface and allowed to penetrate and thus bind the upper portion of the surfacing. Materials sprayed onto the surface include Sandfix and Mobil Dust Palliative. Sandfix consists of a cutback bituminous binder that penetrates up to 8 mm but leaves a bitumen film on the surface that counteracts the formation of dust. A sand binding layer is often used to prevent tackiness of the surface. Mobil Dust Palliative is similar in composition to Sandfix.

Materials mixed into the gravel wearing course include the following:

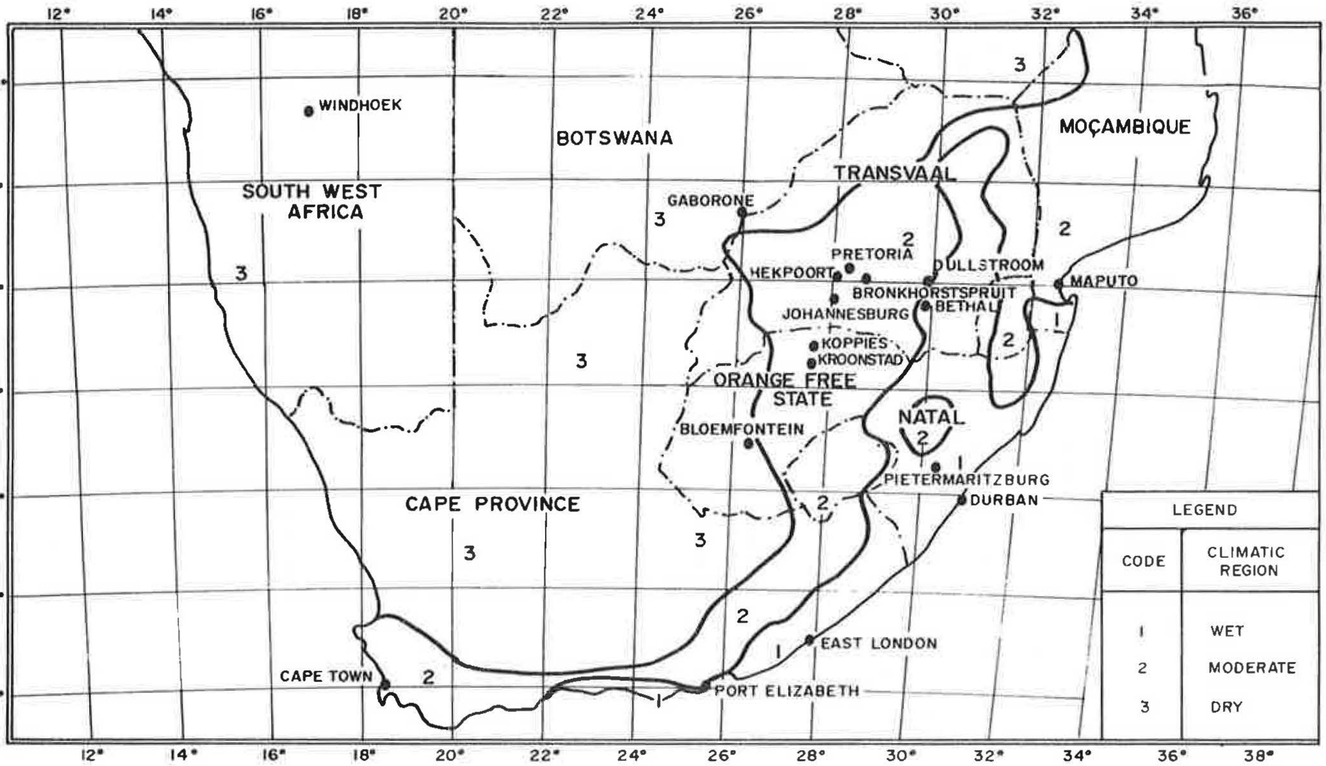
1. Road tar (RTH 15/20)--A 15/20 EVT coke oven tar can be mixed into the upper 150 mm of the gravel wearing course. Problems are sometimes encountered in the application of the tar on the uncompacted base material because the uneven surface affects the distributor when spraying. Furthermore, the binder sticks to the construction equipment.
2. Reynolds Road Packer--Reynolds Road Packer is a chemical material that alters the molecular structure of the clay particles of the gravel and has cementitious properties. It is mixed into the wearing course, dissolved in large quantities of water.
3. Consolid 444 and Conservex--Consolid 444 is a capillary active agent that causes coagulation of the fine particles. It is mixed into the upper 150 mm of the gravel wearing course. Conservex is a bituminous product that mixes uniformly with water. When sprayed, the bituminous drops attach themselves to the soil particles since these particles have a greater affinity for Conservex than for water.

In the Transvaal, a province of South Africa, the Transvaal Roads Department constructed two sets of experimental sections in May-June 1980 to study the performance of different dust palliatives (1). These sections were located on Roads 211 in the Dullstroom district and 703 near Bethal, both in rural areas (Figure 1). Traffic volumes on these roads are about 160 vehicles/day (13 percent heavy vehicles) on Road 211 and 90 vehicles/day (24 percent heavy vehicles) on Road 703. The gravel wearing course was a good-quality lateritic gravel on Road 703 and a weathered sandstone and shale gravel on Road 211. Basic properties were as follows:

Property	Road 703	Road 211
Maximum size (mm)	75	75
Percentage passing		
2-mm sieve	39-47	
0.075-mm sieve	9-17	
Liquid limit	25-33	
Plasticity index	8-13	5-11

Application rates used on the experimental sections

Figure 1. Climatic regions of southern Africa.



are given below (for road tar, binder contents were 2.0 and 1.6 percent by mass of base, respectively):

	Application Rate (L/m²)	
Material	Road 211	Road 703
Sandfix	0.6-1.0	1.3-1.6
Mobil Dust Palliative	0.9-1.2	0.9-1.2
Road tar	6.09	4.68
Reynolds Road Packer	0.4-0.6	0.4-0.6
Consolid 444 + Conservex	0.4 + 1.0	0.5 + 0.9

The aim of the experiments was to introduce these materials to the regional staff and to develop some understanding of their uses and application techniques. Any conclusions drawn so far can only be considered preliminary, and the quality of construction could have an overriding influence.

Two months after construction the sections were inspected (1). On those sections where Sandfix and Mobil Dust Palliative had been applied, cracking and signs of potholing were evident. A year after construction these sections had potholed, and the holes were filled with a bituminous mix by the maintenance gang. After two years this status had been maintained on Road 703, but on Road 211 the situation had deteriorated. The Sandfix section had been ripped up because of extensive potholing that the maintenance team could not contain despite extensive patching. The section treated with Mobil Dust Palliative was extensively potholed, especially near the edge of the traveled way.

Differences in the performance of the materials sprayed onto the surface of the two roads could be attributed either to the quality of the wearing course gravel or to traffic, and further work is necessary to resolve this question. The life of the sections on Road 211 that were treated with the materials sprayed onto the surface can thus be considered as two years or some 100 000 vehicle passes. Further monitoring of the sections on Road 703 is necessary to determine their life span.

A short section of road in the Orange Free State that was treated with Mobil Dust Palliative was inspected three months after construction. The inspection revealed a performance similar to that of the above section, which was treated with the same agent and at the same age. It was evident that the natural variability in the gravel composition resulted in areas of excess fine material where the agent soaked away leaving lean spots. Under traffic action these lean spots abrade rapidly and the result is potholes.

Most of the sections on Road 211 that had materials mixed into the surfacing showed cracking when inspected two months after construction. The amount of dust on these sections had also diminished significantly in comparison with the control section. After a year, the performance of the sections treated with tar, Reynolds Road Packer, and Consolid/Conservex was not meaningfully different from that of the control section in terms of riding quality, but there was slightly less dust. During the first two years, no blading of the treated sections was necessary on Road 703, whereas on Road 211 the sections that had had an agent mixed into the wearing course were bladed, although not as frequently as the rest of the road (two to eight times per year less). After two years, the dust on the sections that had had materials mixed into the surfacing was the same as on the control sections, and there were thus small remaining benefits in terms of reduced blading.

Riding quality measurements were taken on the two sets of experimental sections in the Transvaal after two years of traffic. The averages of three repeat runs are given in Table 1. The roughness scale used is the Quarter-Car Index (QI) (2). The QI was originally developed from simulating the motion of a vehicle over a road profile measured with a General Motors Profilometer and summing the body movement

Table 1. QI measurements on dust palliative experimental sections after two years.

	QI (counts/km)			
	Road 703		Road 211[a]	
Material	South-bound	North-bound	North-bound	South bound
Sandfix	52	65	77[b]	73[b]
Mobil Dust Palliative	56	48	60[b], 97	56[b], 79
Reynolds Road Packer	60	73	47	43
RTH 15/20 Tar	54	33	103	75
Consolid/Conservex	39	36	84	77
Control	87	88	67	58

[a] Maintained regularly. [b] Ripped up.

relative to the wheel axle over a fixed distance. Thus, the result is nominally related to the output of the Bureau of Public Roads Roughometer but not equal in value because of scaling factors. The QI has units of length per length, but to avoid confusion with other roughness measures the units were designated counts per kilometer. QI values on paved roads range from about 10 (very smooth) to about 100, whereas on unpaved roads values as high as 450 have been measured. The QI can also be obtained on any road section by analyzing the road profile measured by normal survey techniques.

The control section on Road 703 was located at the bottom of a sag curve, and extensive erosion had occurred. This is thus not a representative control section. Unfortunately, no riding quality measurements were made at the time of construction, and in the economic evaluation it was assumed that the construction quality was similar for all sections.

From a technical point of view, the agents evaluated have not performed as well as expected. This could be attributable to material selection and construction techniques and control, and further work is necessary to resolve these questions. It is important to note that maintenance on those sections that were treated with a material sprayed onto the surface is labor-intensive, whereas the value of the agent mixed into the wearing course is lost when the material is cut by motor-grader. Besides the technical performance, it is necessary to consider the economics of using dust palliatives. This is discussed later in this paper.

Surface Treatment on Substandard Pavement Structures

By modern standards, the original network of National Roads constructed and paved in South Africa from the late 1930s to the 1950s consisted of substandard pavements. The roads were essentially gravel roads surfaced with a single seal. A granular base layer was often added to the existing gravel road. Yet they served the country very well and in some rural areas are still providing service after their riding quality has been improved with a thin asphaltic overlay. Rapid traffic growth, however, has since led to the adoption of higher standards for both road geometry and pavement structure.

In the early 1960s, it became evident that the geometric and structural standards applied to the primary and secondary road network were too high and thus too costly for most low-volume, lightly trafficked roads of the tertiary network.

Different approaches were used by the different provincial road authorities in South Africa. They are autonomous bodies that control all rural roads except National Roads within their provinces. Thus, the methods used cover a wide range.

Transvaal

A number of roads in the Transvaal were gravel roads that were upgraded to paved standard by the addition of an unstabilized natural gravel base course and a surface treatment. Two of these roads, built in 1955, are discussed in greater detail later in this paper in the discussion of performance results with the HVS. Although these roads have performed very well over a period of 27 years and have carried about 0.5 million to 1.0 million 80-kN equivalent axle loads (EALs), they have not been completely without problems. Short sections often had to be reconstructed early in the lives of these roads.

Orange Free State

The Orange Free State Provincial Roads Department also sought cheaper methods of improving its gravel roads. In many areas of the province, good gravel wearing-course materials are scarce and have to be transported over long distances. Gravel loss on gravel roads therefore has important financial implications. The main aim of paving gravel roads was to protect the structure from both loss of surfacing and the effects of the ingress of moisture. This approach was also applied in Brazil with good results (3).

These roads constructed with a light structure are termed "special secondary roads". To qualify as such, the roads must meet the following requirements (4):

1. The road must not be constructed as a primary road (carrying at least 200 vehicles/day) for five years.
2. Average daily traffic (ADT) must be 80-150 vehicles.
3. The proposed road must not carry through traffic--i.e., it has to be a farm-to-market road.
4. The anticipated rate of traffic growth has to be low--say, less than 5 percent.
5. Suitable material for regraveling the road must not be economically available.

When an existing gravel road is upgraded, the alignment is maintained, if possible, to benefit from traffic compaction over the years. Special attention is given to subsurface as well as surface drainage. The traveled way is 7.4 m wide, and there are 1.5-m-wide gravel shoulders on either side.

Specifications (6) for the pavement require the unstabilized subbase to have a minimum in situ California bearing ratio (CBR) of 35 at 95 percent modified American Association of State Highway and Transportation Officials (AASHTO) compaction, a minimum grading modulus of 1.5, and a maximum plasticity index (PI) of 10. The existing gravel wearing course is brought to a uniform thickness of 150 mm if of suitable quality for the subbase or a new layer is imported. For the natural gravel base (150 mm), an estimated in situ CBR of at least 65 at 98 percent modified AASHTO compaction and a maximum PI of 6 are required.

A bituminous double seal consisting of a layer of 13.2-mm and a layer of 6.7-mm stone is used as a surfacing. The cost of a special secondary road is approximately one-fifth the cost of a primary road, mainly because of savings in earthworks and pavement layers.

A total of 610 km of special secondary roads have been built since the first experiments in 1971. Excellent performance has been recorded on these roads (4). One of these roads, the road from Koppies to Kroonstad, is being reconstructed mainly because of the dramatic increase in traffic. When this road was constructed in 1973, it carried 300 vehicles/day. This would have decreased had the National Road, which was planned to run parallel to this road, been built. However, it was decided to defer construction of the National Road, and the ADT in 1981 was approximately 1100 vehicles/day on some parts of this road. The spectacular traffic growth is due to the fact that this road reduces the distance to be traveled between Kroonstad and the Reef by some 20 km.

These traffic figures illustrate that this road carried far more traffic than was anticipated for the design life of 10 years. The figure of 10 years was considered at the time of construction to be the break-even life between maintaining the original road and the cost of constructing and maintaining the light pavement structure. Because of the heavy traffic, trucks travel on the edge of the pavement and extensive shear failures have occurred near the outer edge. At locations of poor drainage, potholing has occurred and considerable maintenance effort is required.

Natal

In Natal, sand seals to counteract weathering caused by a high annual rainfall have been used with varying degrees of success. They have lasted between two and eight years (5) depending on traffic conditions and materials. A tar prime is used in areas where it is readily available; otherwise, a cutback bitumen is used. First one application, which penetrates, is made, and after about an hour the next spray with a course sand or crusher dust is applied. Increasing binder price, difficulties in procuring sand of the desired quality, and the relatively short life have resulted in the use of a single seal with 6- to 9-mm stone instead of the sand seal in many cases.

General

Several important points about special secondary roads have come to the fore. These roads are constructed to a low geometric and pavement standard, but the traveling public does not appreciate this. When they see a black road surface they travel at high speed, and they do not realize that the geometry may not be adequate. When a road suddenly starts potholing, the traveling public complain about the poor quality of modern paved roads. On the other hand, when these roads perform well under favorable conditions, funding agencies ask why other roads need to be constructed to primary road standards.

A further problem that accelerates the deterioration of these roads is that on a gravel road the farmer is aware that overloading may cause damage to the vehicle but as soon as the road is paved this risk is minimized, overloading occurs, and the road rapidly deteriorates.

PAVEMENT EVALUATION WITH THE HVS

The HVS (see Figure 2) was developed by the National Institute for Transport and Road Research of South Africa. It is used to subject road pavements to accelerated trafficking by the loaded test wheel. The characteristics of the HVS are summarized below:

Characteristic	Value
Overall length (m)	22.56
Overall width (m)	3.73
Overall height (m)	4.20
Total mass (kg)	57 000
Trafficking speed (km/h)	14
Trafficking length (m)	8
Trafficking width (m)	0.6-1.5
Repetitions per hour	1200
Load (kN)	
Static	0-150
Dynamic	0-100
Inflation pressure (kPa)	560-690

Experience in both the Transvaal and the Orange Free State has indicated good performance with light pavement structures. This may be attributable to certain inherent factors in construction or maintenance. As part of the HVS program (6), several light pavement structures were evaluated because these pavements probably best illustrate the behavior of unbound granular base pavements under the repeated application of wheel loads.

Roads P6/1 (Bapsfontein-Bronkhorstspruit) and P123/1 (Hekpoort) in the Transvaal were constructed around 1955, when existing gravel roads were upgraded to paved standard. The pavement structures of the test sites are shown in Figure 3 (7). It should be noted that some of the weakest sections on each road were selected for the tests. The base courses consist of current subbase-standard material. The surfacing of Road P6/1 consisted of old, brittle seal coats, whereas Road P123/1 was resealed about two years before the tests and the surfacing appeared flexible.

The test program is summarized in Table 2 (7). Each test number represents a new test position at the same location. These structures were surprisingly strong and were able to support a large number of repetitions of heavy wheel loads. The applied load repetitions are in addition to the estimated 0.5 million to 1 million 80-kN EALs applied by normal traffic up to the time of testing.

Figure 4 (7) charts the permanent deformation of Road P6/1 under different wheel loads. Surface crack initiation and the addition of water are also shown in the figure. Apart from rainfall, water was added with a sprinkler system. The equivalent of 10 mm of rain was applied every 6 h. This led to a dramatic failure. The condition of this pavement after various wheel-load repetitions is shown in Figure 5.

Test section 43A4 (Table 2) cracked after 30 000 load repetitions of an 80-kN dual wheel. The cracks, however, hardly influenced the behavior of the test section as long as the section remained dry. The number of cracks increased until the section showed distinct crocodile cracking after 100 000 load repetitions (see also Figure 5A). Even after 200 000 repetitions, the permanent deformation was less than 10 mm. A rain shower at 280 000 repetitions resulted in an increase in the rate of deformation, but as the pavement dried out the rate decreased to almost no change. Figure 5B shows the condition after 842 000 load repetitions. At 860 000 repetitions (15.8 million 80-kN EALs), water was sprayed onto the section and within 100 000 load applications the section had disintegrated completely, as Figure 5C shows. This phenomenon is also shown by the rapid increase in permanent deformation. After the test, a cross-section trench was opened and, as in all the tests, most of the deformation was found to have occurred in the base course. This observation is consistent with the in situ CBR values measured by a portable dynamic cone penetrometer (DCP) (8) after the test (see Figure 6). The loss of strength was confined to the wetted base and subbase material.

These results also have an important bearing on the question of whether or not we are overdesigning by using the soaked CBR in pavement design. Substandard materials often have adequate bearing strength when kept dry but lose considerable support when they become soaked (9). When maintenance operations are directed toward keeping the pavement materials dry, the substandard materials perform adequately, as this paper shows. When the allocation of funds for maintenance cannot be relied on

Figure 2. Heavy vehicle simulator.

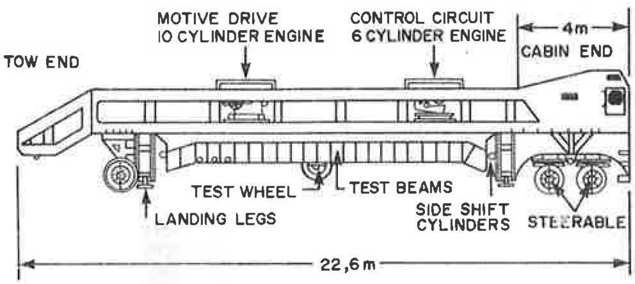


Figure 3. Pavement structures tested on Roads P6/1 and P123/1.

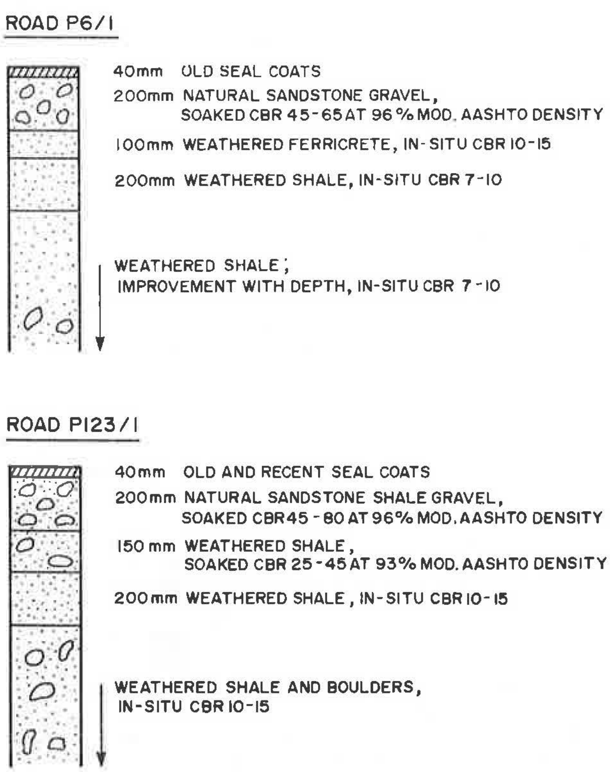


Table 2. Load repetitions of different wheel loads at different stages of deterioration on Roads P6/1 and P123/1.

Road	Test No.	Dual Wheel Load (kN)	No. of Repetitions to Crack Initiation	No. of Repetions for 20-mm Deformation (000 000s) Normal Condition	Wet Condition
P6/1	45A4	40	100 000	>10	0.014
	43A4	80	30 000	1.000	0.022
	44A4	100	10 000	0.150	0.016
P123/1	76A4	40	200 000	0.500	0.040
	77A4	60	380 000	0.650	0.080
	75A4	100	15 000	0.080	0.030
	92A4	40	300 000	0.700	0.150
	91A4	100	5 000	0.015	-

and there is thus uncertainty about being able to carry out a reseal when necessary, it could be dangerous to design based on the unsoaked CBR, especially for the upper layers in the pavement.

On Road P123/1, the mode of deterioration corresponded very well with what occurred on Road P6/1. Because the surfacing was fairly new, the cracking started about two to three times later than it did on Road P6/1, which had an old, brittle surfacing. This result indicates the value of regular maintenance in the form of reseals.

Table 2 gives the number of load repetitions necessary for crack initiation as well as for 20-mm deformation in the wet and dry states. These results clearly illustrate the overwhelming effect of moisture on cracked light pavement structures. It is also apparent that Road P123/1, which had a younger and fresher surface seal, could withstand more load repetitions before cracking than Road P6/1 (9). Load equivalency factors (7,10) were calculated from these tests, and it was found that the moisture also influences the load equivalency factors to such an extent that in the wet condition even car wheel loads may contribute to the distress. For such conditions, it may be appropriate to consider vehicle passes as well as 80-kN EALs as the criterion for damage.

ECONOMIC EVALUATIONS OF LIGHT PAVEMENT STRUCTURES

The MDS (11, 12, and a paper by Visser and Hudson elsewhere in this Record) was used to perform the economic computations. The MDS combines unpaved

Figure 4. Permanent deformation of structure of Road P6/1 as measured in HVS tests.

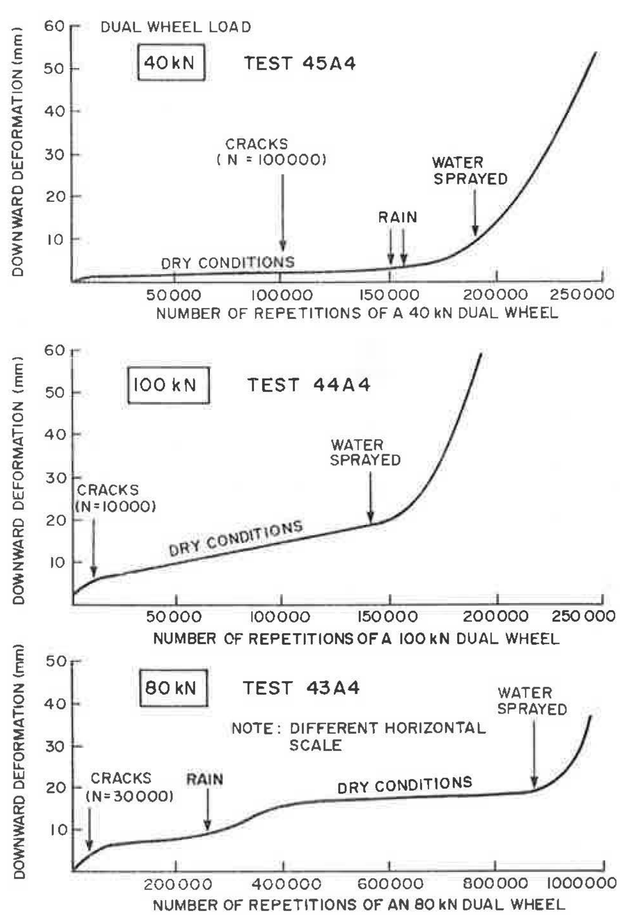
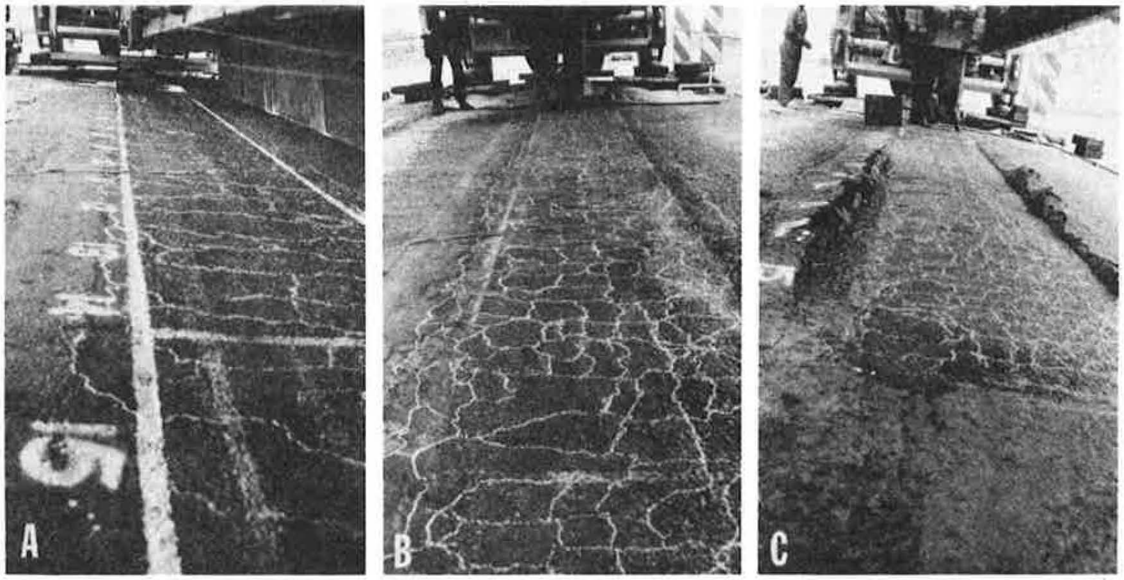


Figure 5. General condition of test section 43A4 after varying numbers of 80-kN wheel load applications: (A) N = 120 000, cracking increasing; (B) N = 842 000, cracking increasing continuously, slow deterioration; and (C) N = 964 000, end of test (rapid deterioration after addition of water at N = 862 000).



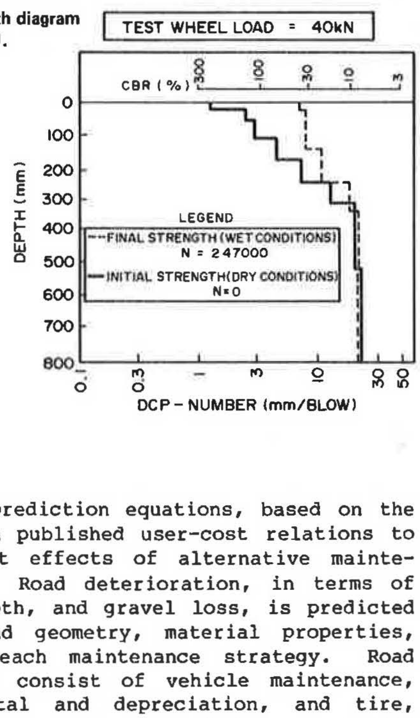


Figure 6. DCP layer-strength diagram for test 45A4 on Road P6/1.

road performance prediction equations, based on the Brazil study, with published user-cost relations to determine the cost effects of alternative maintenance strategies. Road deterioration, in terms of roughness, rut depth, and gravel loss, is predicted from traffic, road geometry, material properties, and climate for each maintenance strategy. Road user costs, which consist of vehicle maintenance, interest on capital and depreciation, and tire, fuel, and oil costs, are then computed for each road condition. The evaluation considers minimizing the total cost, which is the sum of maintenance cost, regraveling cost, and road user costs, in determining the optimal maintenance strategies for unpaved roads. The road user cost subroutine was used to compute the user costs on paved roads, given road roughness.

Road improvements must fulfill two economic criteria (13):

1. The ratio of the savings in road user costs and road maintenance costs to the cost of improvements should at least equal the relevant interest rate for the first year after construction. This is termed the first-year-benefits rule.
2. The total benefits over the life of the pavement should exceed the total cost of improvements.

In the analyses, a real discount rate of 10 percent, currently suggested for South African conditions, was used.

Dust Palliatives

For the exercise, a three-year life span for the sections treated with dust palliatives under an ADT of 70 cars and 20 trucks was considered. Based on Table 1 and experience, average roughness values (QI) during each analysis year are 30, 50, and 80. Table 3 gives the different cost elements for the gravel road and the road treated with a dust palliative; the construction costs are given below:

	Cost (1980 R)	
Material	Road 211	Road 703
RTH 15/20 tar	13 930	8 910
Reynolds Road Packer	8 220	8 400
Consolid-Conservex	13 360	9 260
Sandfix	6 020	5 060
Mobil Dust Palliative	3 120	3 510

From Table 3, in terms of the first-year savings of R1006 for the least-total-cost maintenance strategy, pavements that can be constructed with dust palliative materials for less than R10 000/km give a return greater than 10 percent. This return is better still if the optimum maintenance strategy cannot be applied to the gravel road: Savings are R1208, which gives a return of 12 percent. For the section treated with Mobil Dust Palliative, the first-year benefits are 39 percent for suboptimum maintenance cases (benefits of R1208) (Table 3) divided by construction cost of R3120 (from the table above). Thus, the first economic criterion is fulfilled. However, when the total costs and benefits over the three-year life span are compared, it is obvious that the benefits (R1179 from Table 3) are considerably less than the costs of construction (R3120 from the table above) even when the maintenance costs on the dust palliative sections are not included. The rapid deterioration of the riding quality results in user costs over the last 18 months being greater than on the gravel road, even when the gravel road is maintained suboptimally at two-thirds of the optimum maintenance cost.

Table 3. Comparison of cost on dust palliative and gravel road sections and benefits of using dust palliatives.

Item	Costs (R/km) Dust Palliative Section	Gravel Section	Savings (R/km)
First Year: Least Total Cost Strategy on Gravel Road			
Road user costs	4 547	5 207	654
Grader costs	-	192	192
Regraveling costs	-	160	160
Total savings			1006
First Year: Grader Costs = Two-Thirds Optimum			
Road user costs	4 547	5 471	924
Grader costs	-	124	124
Regraveling costs	-	160	160
Total savings			1208
Three-Year Life: Least Total Cost Strategy on Gravel Road			
Road user costs	14 014	14 227	213
Grader costs	-	526	526
Regraveling costs	-	440	440
Total savings			1179
Three-Year Life: Grader Costs = Two-Thirds Optimum			
Road user costs	14 014	15 000	986
Grader costs	-	339	339
Regravelling costs	-	440	440
Total savings			1765

Note: Costs and savings are given in 1980 South African Rand (R) values. In 1980, R1 = approximately U.S. $1.

Table 4. Discounted benefits on road sections with a light pavement structure in comparison with gravel road.

Average Daily Traffic (no. of vehicles)	Reduction (R/km) Road User Costs	Grader Costs	Regraveling Costs	Total
First Year: Least Total Cost Strategy on Gravel Roads				
100	925	315	258	1 498
127	1 167	356	277	1 800[a]
200	1 820	462	328	2 610
300	2 795	609	400	3 804
400	3 858	685	470	5 013
500	5 324	618	542	6 484
First Year: Grader Costs = Two-Thirds Optimum				
100	1 164	202	258	1 624
115	1 312	219	269	1 800[a]
200	2 150	319	328	2 797
300	3 126	394	400	3 920
400	4 324	470	470	5 264
500	6 204	403	542	7 149
Ten-Year Life: Least Total Cost Strategy on Gravel Roads				
100	5 337	2130	1744	9 211
200	10 368	3123	2217	15 708
233	12 202	3420	2378	18 000[b]
300	15 926	4120	2704	22 750
450	22 105	4636	3177	29 918
500	31 094	4183	3663	38 940
Ten-Year Life: Grader Costs = Two-Thirds Optimum				
100	7 116	1372	1744	10 232
200	12 727	2163	2217	17 107
214	13 513	2202	2285	18 000[b]
300	18 339	2668	2704	23 711
400	25 425	3179	3177	31 781
500	37 403	2727	3663	43 793

[a]Cost figure for expected rate of return. [b]Cost figure at break-even traffic volume.

Some sections behaved better than the assumed performance (QI values of 30, 50, and 80 for each analysis year), and the calculation was repeated with QI values of 30, 40, and 50 for the first, second, and third years. Even under such favorable conditions, the total benefits amount to only R2100, which is still less than R3120. Besides being technically unsatisfactory, the treatment of gravel roads with a dust palliative is therefore uneconomical for the life span of the section, although initially, while the road is in a good condition, there are distinct benefits. In an independent evaluation (14), the Transvaal Roads Department arrived at the same conclusions, although the Department believes that there is merit in using dust palliatives and further test sections will be constructed with improved construction techniques and quality control.

Light Pavement Structures

From a technical point of view, the light pavement structures have performed very well. Recent roughness measurements on Road P6/1, after 25 years of trafficking, indicated an average road roughness of 40 QI and a standard deviation of 12 QI for 100-m lengths. These roughness measurements do not reflect the behavior of the sections that failed and were rebuilt early in the life of the pavement. This type of performance is exceptional, and in the economic evaluation it is assumed that this roughness level is reached in 10 years. The economics of this paved road were compared with those of typical gravel roads. The gravel road evaluated for comparison has a quartzitic gravel wearing course with 25 percent of the material passing the 0.075-mm sieve and a PI of 6, which is typical for the central Transvaal. The cost of the gravel placed was R2/m^3, which is typical for South African conditions. Higher gravel costs may justify paving at an earlier stage.

Different traffic volumes were investigated, but in all cases cars constituted 80 percent, buses 2 percent, medium trucks 10 percent, and heavy trucks 8 percent of the total traffic volume.

The user costs for the paved and unpaved roads, as well as the regraveling and grader costs, were again computed by the MDS program. Table 4 gives the discounted benefits of paving--i.e., the reduction in discounted costs for the gravel road due to paving. The total benefits can be compared with the estimated cost of R15 000 for constructing a bituminous surface treatment and priming at the time a gravel road is constructed or regraveled and the cost of a single reseal after six years at a discounted cost of R3000. These costs amount to a total cost of R18 000, excluding the cost of regraveling. If the expected rate of return of first-year benefits is at least 10 percent, then the benefits should be at least R1800. The data given in Table 4 indicate that this situation is reached for traffic volumes of 110-130 vehicles/day for both maintenance levels. However, because of the relatively short analysis period, the total benefits are the significant criterion. For this criterion, traffic volumes must be greater than about 230 vehicles for the high level of gravel road maintenance and about 210 for the lower maintenance level for the given construction costs. Different pavement construction costs can be evaluated in a similar manner, and the break-even traffic volume can be determined. These results show that the light pavement structure, which is also considered to provide protection for the gravel road structure, is economically viable at fairly low traffic volumes for the cost combinations given. This is true despite the expected 10-year life span of the pavement.

Despite the fact that light pavement structures are an economical proposition, it is important to note that maintenance funds must be available for resealing the road. If not, the road could disintegrate virtually overnight in a wet season. Care should also be taken that technical facilities are available for the sealing and resealing operations when they become necessary. In certain cases, it may be better to construct a pavement designed to accepted standards rather than carry out a temporary improvement, but each case would have to be considered on its merits. When there is uncertainty about the supply of maintenance funds, it may be better to keep the road as a gravel road, since a blading operation can restore the riding quality of a gravel section but costly reconstruction would be necessary to rehabilitate a badly deteriorated paved section.

CONCLUSIONS

Gravel roads can be improved by applying dust palliatives, or they can be upgraded to a light pavement structure with a surface treatment. Experience with the dust palliative agents evaluated in this research showed that they crack fairly early in their life and thereafter deteriorate rapidly. They appear to have a life span of one to three years when traffic volume is about 100 vehicles/day. Dust and maintenance were reduced, but at this stage the performance of dust palliatives has been less than satisfactory from a technical point of view and further research is required with regard to materials, construction techniques, and control. The economic evaluation of the constructed experimental sections showed that this type of treatment was uneconomical.

On the other hand, experience in South Africa indicates that good performance can be achieved with light pavement structures. Tests with the HVS showed that good performance is partly attributable to timely and effective resealing, which ensures that water does not get into the pavement. The tests also showed that the pavement disintegrates rapidly when moisture enters the structure through cracks in the surfacing. However, when kept dry these pavements can carry more than a million 80-kN EALs. This also means that good drainage must be provided to ensure that water cannot pond close to the road. If regular resealing can be achieved, materials that have an adequate CBR when unsoaked but are substandard when soaked could perform satisfactorily, although it is safer to use soaked CBR values in designing the upper pavement layers. In wet conditions, even car wheel loads may contribute to distress. It may be appropriate to consider vehicle passes as well as 80-kN EALs if the surfacing is cracked and moisture enters into such pavements.

The economic evaluation showed that surfacing of a gravel road is viable at traffic volumes as low as 230 vehicles/day when the construction and discounted maintenance cost is R18 000/km. Insufficient funding for maintenance of gravel roads decreases this break-even traffic volume. Under conditions of insufficient funding, it may be safer to keep the gravel road. It is imperative that the money be available for resealing when such repair is required; otherwise, total disintegration could occur, which would make paving totally uneconomical.

REFERENCES

1. Dust Palliatives: The Construction of Experimental Sections in the Transvaal (in Afrikaans). Materials Branch, Transvaal Roads Department, Pretoria, South Africa, Internal Repts., May 1979-Sept. 1980.
2. A.T. Visser and C.A.V. Queiroz. Roughness Measurement Systems. In Research on the Interrelationships Between Costs of Highway Construction, Maintenance, and Utilization, GEIPOT, Brasilia, Brazil, Working Document 10, July 1979.
3. H. Utiyama, J.S. Nogami, F.C. Correa, and D.F. Vilibor. Pavimentacâo Economica: Solo Areno Fino. Revista DER, No. 124, DER Sao Paulo, Brazil, May 1977.
4. J.A. Venter. Construction and Maintenance of Gravel Roads in the Orange Free State (in Afrikaans). Presented at Symposium on Road Aspects, Bloemfontein, South Africa, April 24, 1980.
5. Structural Design of Interurban and Rural Road Pavements. Council for Scientific and Industrial Research, National Institute for Transport and Road Research, Pretoria, South Africa, Draft TRH4, 1980.
6. C.R. Freeme, R.G. Meyer, and B. Shackel. A Method for Assessing the Adequacy of Road Pavement Structures Using a Heavy Vehicle Simulator. Proc., 9th World Meeting of International Road Federation, Stockholm, Sweden, Vol. TS-5, June 1981, pp. 151-167.
7. J.H. Maree. Heavy Vehicle Simulator Tests on Light Pavement Structures with Granular Base Layers (in Afrikaans). Council for Scientific and Industrial Research, National Institute for Transport and Road Research, Pretoria, South Africa, NITRR Tech. Rept. RP/19/82, 1982.
8. E.G. Kleyn, J.H. Maree, and P.F. Savage. The Application of a Portable Pavement Dynamic Cone Penetrometer to Determine In Situ Bearing Properties of Road Pavement Layers and Subgrades in South Africa. Presented at 2nd European Symposium on Penetration Testing, The Hague, May 1982.
9. G.P. Marais, J.H. Maree, and E.G. Kleyn. The Impact of HVS Testing on Transvaal Pavement Design. Presented at Annual Transport Convention, Council for Scientific and Industrial Research, Pretoria, South Africa, 1982.
10. J.H. Maree. Aspects of the Design and Behaviour of Pavements with Granular Base Layers (in Afrikaans). Univ. of Pretoria, Pretoria, South Africa, D.Sc. dissertation, 1982.
11. A.T. Visser. An Evaluation of Unpaved Road Performance and Maintenance. Univ. of Texas at Austin, Ph.D. dissertation, May 1981.
12. A.T. Visser and W.R. Hudson. Design and Maintenance Criteria for Unpaved Roads. Civil Engineer in South Africa, Vol. 25, No. 2, Feb. 1983.
13. C.G. Harral, T. Watanatada, and P. Fossberg. The Highway Design and Maintenance Standard Model (HDM): Model Structure, Empirical Foundations and Applications. Presented at 2nd International Conference on Low-Volume Roads, Ames, IA, Aug. 21, 1979.
14. M.J.J. Van Heerden. Dust Palliatives: Experimental Sections on Roads 211 and 703 (in Afrikaans). Materials Branch, Transvaal Roads Department, Pretoria, South Africa, Internal Rept. S2/82, Oct. 1982.