PERFORMANCE LIMITS FOR BITUMINOUS SURFACINGS ON LOW VOLUME ROADS

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SUMMARY

The performance limits for bituminous surfacings on low volume roads were investigated as part of a SABITA research project into appropriate standards for bituminous roads. A wide range of surfacing types were investigated at sites in urban areas, townships, and rural areas across South Africa. It was found that the most important factors affecting the performance of surfacings on these low volume roads were environment, gradient (covering shoving of the surfacing, and damage due to water running along the surfacing), and maintenance. Four distinct environments were identified in South Africa: First World high standard pavements; First World lower standard pavements; Third World; and Wet/Hilly. Performance limits have been recommended to ensure the selection of appropriate surfacings for the full range of conditions and environments.

OPSOMMING

Die effektiwiteit van bitumineuse deklae op lae volume paaie is ondersoek as deel van 'n SABITA navorsingsprojek wat gerig was op toepaslike standaarde vir bitumineuse paaie. 'n Wye verskeidenheid deklaagtipes is dwarsoor Suid Afrika in gegoede en minder gegoede voorstedelike woongebiede en in die platteland ondersoek.

Tydens die ondersoek is gevind dat omgewing, padhelling (deklaagskuif en skade as gevolg van watervloei) en instandhouding die belangrikste invloedsfaktore op die prestasie van die deklae op lae volume paaie is. Vier omgewings met merkbare verskille is geidentifiseer, naamlik Eerste wêreld hoë standaard plaveisels; Eerste wêreld laer standaard plaveisels; Derde wêreld; en Nat/Bergagtig. Aanbevelings word gemaak ten opsigte van perke vir goeie prestasie om te verseker dat die regte keuse gemaak word met inagneming van die volle spektrum van toestande en omgewings.

INTRODUCTION

The performance of bituminous surfacings on low volume roads was investigated as part of a SABITA-sponsored research project into appropriate standards for bituminous surfacings[1]. The research was into cost-effective bituminous surfacings for low volume roads. A key issue in cost effectiveness is the time to reseal, and it became clear that the performance of the surfacing was as much an issue as its construction cost. If a surfacing is used in an inappropriate situation, its performance can be unacceptably low; this is particularly true in urban and township situations. In this paper the performance limits for bituminous surfacings on low volume roads are derived.

The data on the performance of surfacings was collected by a programme of field and laboratory work which covered 98 sites on the Reef, North/Eastern Transvaal, Western Transvaal, Vaal Triangle, Durban/Natal, OFS, Eastern Cape, and Western Cape. A wide range of surfacing types was investigated including single, double, and combination seals, asphalt, slurries, quickset slurries, and dust palliatives. The sites were in urban areas, townships, and rural areas, and covered a full range of climates, pavement structures and drainage systems.

EXPERIMENTAL PROGRAMME

Experimental design

It was seen as important to investigate as large a number of different surfacings as possible in order to determine the influence of a full range of external factors. There are many factors influencing the performance of surfacings and these factors interact and confound each other in a complex fashion. In order to test across the range of the expected important factors, a factorial experimental design approach was adopted (Figure 1).

Figure 1: Experimental Design

DRAINAGE	URBAN		RURAL	
PAVEMENT STRUCTURE	Standard	Non-standard	Standard	Non-standard
Wet climate (Im > 0)	X	X	X	X
Dry climate (Im < 0)	X	X	X	X

In the experimental design[2], the main factors were:

Climate Thornthwaite's moisture index (I_m) was used which is a measure of evaporation and rainfall and thus an indirect measure of oxidation and aggregate disintegration. Wet climate was $I_m > 0$, and a dry climate was $I_m < 0$.

Drainage Urban drainage was defined as boxed in construction, usually with kerbs, and with water carried longitudinally on the surfacing; rural drainage was defined as shoulders and water runs off the surface transversely.

Pavement structure A standard (adequately strong) pavement structure was defined as one which met the requirements of TRH 3, 4, and 14; had a minimum layer thickness of 100mm in the basecourse and 125mm in the subbase; had a minimum basecourse field DCP-CBR of 80, and subbase field DCP-CBR of 45; and had a DCP count of at least 88 blows from the surface to a depth of 800mm (DSN_{800}). A non-standard (weak) pavement structure was deficient in one or more of these criteria.

Field and laboratory work

The fieldwork was performed in two stages: the first stage was to visit the site, perform the various measurements and tests, and take samples for laboratory testing. The second stage was to revisit each site and perform an inspection by a panel of experienced engineers familiar with seal evaluation. The field testing and laboratory testing included:

DCP test	Skid resistance
Surfacing permeability	Basecourse sample
Rut depth	Seal/base adhesion
Gradients	Visual assessment

The experienced engineers panel had the field and laboratory test results for each section with them during their field visit. The panel made a visual assessment of the performance of each section of road according to TRH 6[3] and the Transvaal Provincial Administration Pavement Management System forms. This assessment differentiated between surface distress caused by structural or drainage inadequacies, that attributable solely to surfacing deficiencies, and that attributable to the use of sub-standard materials. Then the panel evaluated surfacing performance to assess its potential life under the prevailing environmental, traffic, pavement and drainage conditions, and to note specific limitations of the surfacing type.

INITIAL RESULTS

General performance

The performance of the bituminous surfacings ranged from good to poor. In some cases this was as a result of construction problems, but in many cases the poor performance was a result of the surfacing being using in an inappropriate context.

The panel were surprised at the poor performance of some surfacings in townships, even though the construction appeared to have been adequate and the surfacing types were known to perform well on rural roads. It became apparent that surfacing performance on townships and urban roads is influenced by stresses which are not usually experienced on rural roads. One such stress was induced by the actions of people living adjacent to the road, leading to water and sewerage running on the surfacing, garbage strewn on the surfacing, and damage to the surfacing by trenches dug for house services and by construction vehicles. This stress was initially termed "population stress" and was calculated as a function of population density and population social class. Sophisticated statistical analysis later defined this in terms of "environment". Another stress for some roads came from the lack of even basic maintenance to the surfacing.

The bitumen surfacing types which performed best under these high stress conditions were the thicker ones such as asphalt and thick slurries. The use of a very thin bituminous surfacing (such as a dust palliative or single seal) for low cost upgrading in high stress areas such as townships and urban areas appears contra-indicated by this project; although these surfacings can give good performance on low stress rural roads. One observation made several times during the fieldwork was that for low volume roads, the overall road may be more cost effective and perform better by using thicker bitumen surfacings with thin pavements and lower quality pavement materials in contrast to thin bitumen surfacings with high quality pavement materials and thick pavement layers. There is a minimum acceptable standard of pavement materials and structure for good performance, but for low volume roads this can be low.

It also became apparent that a choice of surfacing type must be made for each different set of conditions. One should not assume that any previous good experience with a particular surfacing type is applicable for different environmental conditions. This is particularly true when moving from rural roads to urban roads.

Performance of individual surfacing types

The performance of individual surfacing types was assessed during the fieldwork by a series of interviews[4] and by various lifecycle cost calculations[1]. As a result, a number of comments were compiled for each of the surfacing types. These comments are reproduced here, not as a design prescription, but rather for background information to the designers.

ASPHALT — Excellent performance under all conditions. Requires asphalt plant nearby and good quality control. High construction cost, the lifecycle cost is very competitive despite the higher construction cost, generally maintenance free, poor if very weak pavement structure. Excellent for urban and township roads. The smooth strong appearance gives an image of a high quality surfacing. Good for areas where the road forms a large part of the habitat. Good if the road is used as a playground. This is the lowest risk surfacing of all. General agreement that minimum thickness required is 25mm, but a few believe that 20mm can be laid.

CAPE SEAL	Good performance under most conditions. Reported to need good quality control during its construction. Popular for intersections in cases where the rest of the road is chip and spray. The smooth strong appearance gives an image of a high quality surfacing. Good for areas where the road forms a large part of the habitat. Still appropriate if the road is used as a playground. This is a medium risk surfacing. It is a stiff surfacing which can cause problems on roads with weak pavement layers.
DOUBLE SEAL	(Including both stone/stone and stone/sand seals where there are at least two engineered applications of binder) Good performance in rural areas and fair performance in urban areas. Needs at least 50 v.p.d. to keep binder active in order to prevent stone loss. This is a medium risk surfacing. In an engineered application with a second spray of bitumen, the use of sand as the second application of aggregate has the advantage that the sand binds the lower layer of stone and reduces complaints about broken windscreens. However the sand forms a stiff seal and it was observed that this gave problems on roads with weak pavement layers. Not as good for areas where the road forms a large part of the habitat (although like all bitumen surfacings it is vastly superior to an unsurfaced road). Rare for it to be used by children as a playground due to surface roughness.
SLURRY	When used as an initial surfacing, reasonable performance if thick (at least 12mm), and poor performance if thin (6mm). A number of technical advantages when used as a reseal. It is vulnerable to pedestrian and vehicle damage while fresh. As an initial surfacing it should be applied in two layers each of 6-10mm since a single 6mm layer will ravel quickly due to inadequate depth on high spots in base. Thin slurry is not recommended on its own as an initial seal. Suitable for labour enhanced construction. This is a medium risk surfacing. The smooth appearance gives an image of a quality surfacing. Good

for areas where the road forms a large part of the habitat. Good if the road is used as a playground. The quickset slurries are very useful where road closure time is limited, or in shade or cool weather. It is a stiff surfacing which can cause problems on roads with weak pavement layers.

SINGLE SEAL	Fair to poor performance. Often gives problems due to nozzle blockages and other defects during construction especially when base is not primed. It is acceptable only if good construction and above average maintenance is expected. This is a high risk surfacing.
SAND SEAL	Fair performance if thick, and fair to poor performance if thin. Used as a temporary surfacing in rural applications, where it is resurfaced (often with a second sand seal) within a year. Botswana report good performance from thick graded sand seals (Otta seals). This is a high risk surfacing if thin, and medium risk if thick. It is a stiff surfacing which can cause problems on roads with weak pavement layers. A good maintenance capability is needed.
DUST PALLIATIVE	Fair to poor performance. It is more of a temporary surfacing. It is vital to reseal timeously before maintenance costs rise. Not suitable for low maintenance environments. This is a high risk surfacing. Can be a good temporary surfacing prior to stone reseal.

PERFORMANCE LIMITS FOR BITUMEN SURFACINGS

The performance limits were found from the fieldwork and from a series of interviews with road authorities, consultants and contractors[4]. It was found that there were three main aspects to be considered: environment, maintenance capability, and gradient. The surfacing must be acceptable according to all three criteria to give good performance.

Environment

Environment in terms of climate, urban/rural, and socio-economic aspects is a major factor in determining surfacing performance. There were 22 variables which were available to describe environment; these include population stress, drainage, housing density, basecourse PI, social class etc. These were too many to describe the environment, and factor analysis was used to extract the underlying factors[5]. The goals of factor analysis are to represent the relationships between the environmental variables parsimoniously using factors that are meaningful. The method used for factor analysis was principal components analysis. Varimax rotation was used to minimize the number of variables that have high loadings on a factor. From this, four main environments were found for bitumen surfacing selection in South Africa:

First world high pavement standards	Busier roads, well constructed surfacing, good pavement structure.
First world lower pavement standards	Light pavements with rural drainage but including some urban areas, not mountainous.
Wet/hilly	Mountainous, Thornthwaite's climatic Im>0, typically wet areas of Natal, Eastern Transvaal, and Eastern Cape.
Third world	Generally urban, generally lower socio-economic groups, dense housing, urban drainage, little or no maintenance capability.

Once the environments were identified, many of the observations discussed under general performance earlier in this paper could be seen in a new context. The surfacing design knowledge (such as TRH3[6] had been built up in the first world environment, primarily on the high quality pavements. There is a significant difference between that and the other environments. The factors which are important in selecting bituminous surfacings for first world applications can become relatively unimportant in selecting surfacings for other environments, and a range of new factors must be considered.

The performance limits for bituminous surfacings for low volume roads in terms of environment are given in Table 1.

Table 1 Performance limits for bituminous surfacings for low volume roads

ENVIRONMENT	SURFACING RECOMMENDATION
First world - high pavement standards	Any
First world - lower pavement standards	Any: caution with thin surfacings because they need timeous maintenance; refer to Table 2
Wet / hilly [a]	Refer to Tables 2 and 3
Third world [a]	Refer to Tables 2 and 3

Note: a) no direct recommendation possible due to the wide variation in conditions. Asphalt is the only surfacing which showed up as consistently appropriate.

Maintenance capability

The maintenance capability of the road authority has a major effect on the performance of the surfacing. The maintenance must include all of major items such as reseals or fogsprays timeously applied, routine items such as pothole repair, and items such as street cleaning and soil wash removal. The observed capabilities of the various road authorities varies widely depending on institutional capability and levels of funding. The reasons for the variation include the level of expertise in the road authority, the funds availability, security problems (risk, riots etc), and the ability of personnel.

Surfacings which were maintained in time often had a longer average life and had a lower lifecycle cost (Figure 2). These are averages and, for example, a dust palliative used in an inappropriate context could cost double the figures of Table 2. Asphalt was less sensitive to maintenance than the thinner surfacings such as dust palliatives or sand seals. It was observed that light seals could give good performance provided they received adequate maintenance.

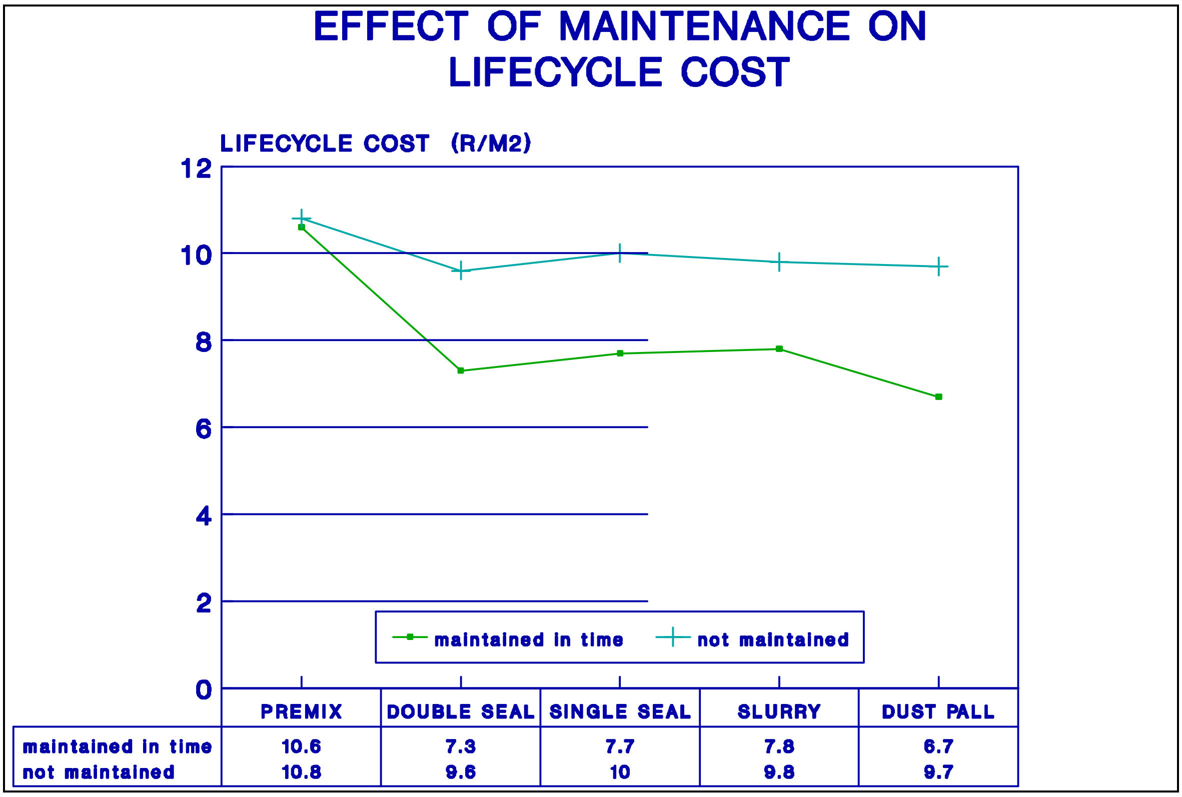

Figure 2

An argument often encountered during this project was "if only this surfacing had been maintained it would have lasted". However numerous examples were seen of surfacings which performed well in nil maintenance environments. Outside the first world high standard environment, maintenance must be considered as part of the stresses operating on the surfacing and the appropriate surfacing selected to cope with that.

The selection of surfacing according to maintenance capability is inter-related with construction quality. In areas of nil maintenance, it was observed that the inevitable construction quality problems were not repaired. Accordingly it is recommended that only surfacings which are less likely to give construction quality problems should be used in the lower maintenance environments. The selection of surfacing according to maintenance capability is recommended in Table 2.

Table 2 Maintenance capability

MAINTENANCE CAPABILITY	DEFINITION	SURFACING RECOMMENDED
High	Can perform any type of maintenance, whenever needed	Any
Medium	Routine maintenance, patching and crack sealing on a regular basis, but no formal MMS[d]	Asphalt, Cape Seal, slurry[a], double seal, single seal[b]
Low	Patching done irregularly, no committed team, no inspection system	Asphalt, Cape Seal, thick slurry, double seal[c]
None	No maintenance	Asphalt

Notes a: Thin slurries are sensitive to construction problems

b: Rural only

c: This is sensitive to construction problems and should only be used where there is good provision for maintenance by the contractor before accepted by the authority.

d: A formal maintenance management system (MMS) is not in itself essential but its presence indicates a level of sophistication

Gradient

Gradient can affect the performance of the surfacing causing either shoving or water erosion. Shoving occurs when the bituminous surfacing slips across the basecourse, and for this reason shoving limits are applicable to an initial seal. It is much less common to find shoving of a reseal and in such cases there is either a built-in construction defect i.e. (lack of tack coat) or the underlying surfacing is already shoving and the reseal merely adds to the problem. Shoving is affected by the basecourse: a rough basecourse is more resistant to shoving than a smooth one. A stabilized fine graded basecourse is sensitive to shoving, and this is accentuated on small radius curves and with heavy vehicles. A basecourse with a thin layer of fines at the top may lead to shoving.

Water damage is the other widespread problem with steep gradients where water flowing along the bituminous surfacing causes damage. There is a maximum water velocity for each type of surfacing before the surfacing gets damaged due to stone plucking and scour. Such water velocity limits are not yet defined, and gradient was used as an indication of water velocity to give limits for surfacings. The gradient does not take into account stormwater design or catchpit layout and therefore the maximum water capacity of each section of road, but it is a reasonable approximation at the present state-of-the art. The gradient limit was observed to vary with the suspended solids in the stormwater, and with a high level of suspended soils there was observable abrasion at relatively moderate water velocities. In areas with poor street cleaning (third world environment), the soil wash concentrated the water flow into channels on the surface and damage was done to the surfacing at relatively shallow gradient vectors.

Surfacings sensitive to water damage were the stone and sand seals (single seal, double seal, sand seal, and dust palliative). It was observed that once these surfacings were damaged, the rate of spread of damage was high and unless there was a good maintenance capability, the road deteriorated rapidly and could be destroyed. The performance of bitumen rubber binders on steep gradients was observed at several sites; there was a slight reduction in loss of stone, little difference in loss of binder, and no difference in overall damage due to water and soil wash; accordingly no difference in recommendation could be made for modified binders.

The performance limits were set from interviews with road authorities, consultants, and contractors[4] and by assessing the performance of the individual surfacing types at the various sites in the fieldwork. This is shown for double seals in Figure 3.

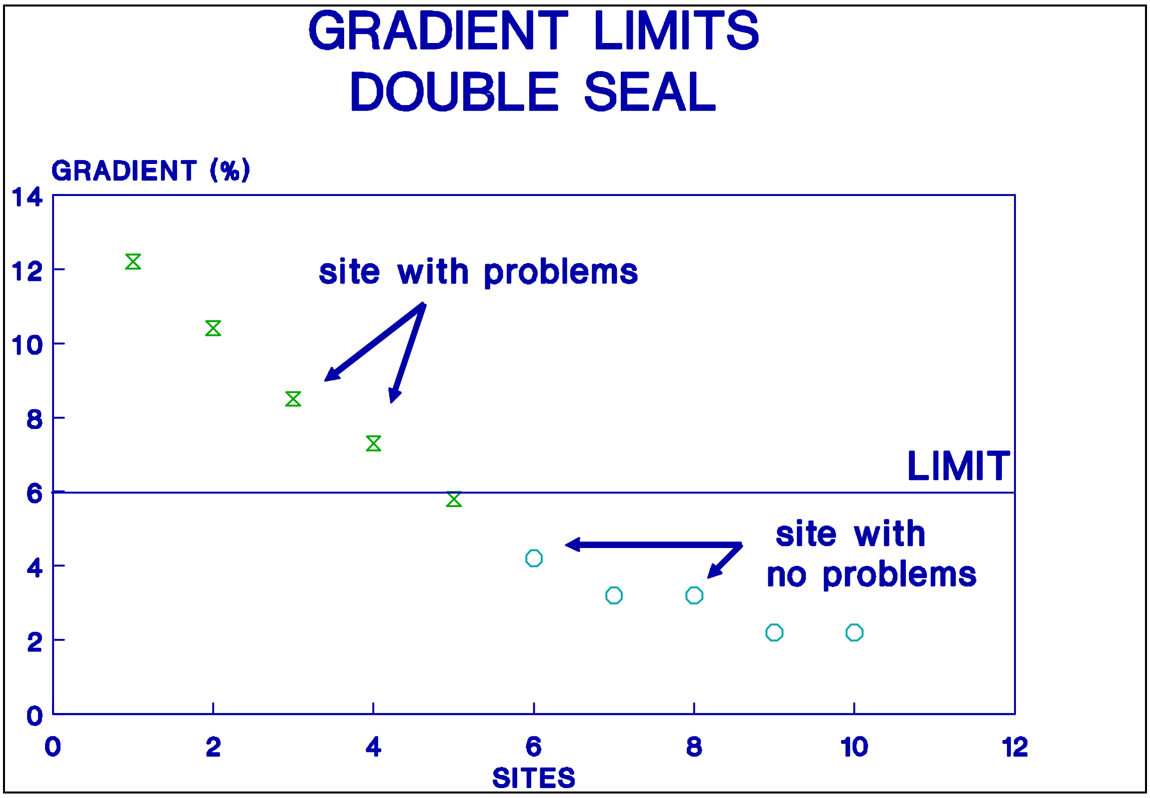

Figure 3

The performance limits for gradients to avoid shoving and/or water damage to the surfacing are recommended in Table 3.

Table 3 Gradient limit

GRADIENT	SURFACING RECOMMENDATION FOR INITIAL SURFACING
< 6%	any surfacing
6 - 8%	asphalt, Cape Seal[d], thick slurry[ad], double seal[cd], single seal[bcd], sand seal[bc]
8 - 12%	asphalt, Cape Seal[de], double seal[cde], single seal[abcde], sand seal[abc]
12 - 16%	asphalt, Cape Seal[ad], double seal[acd]
> 16%	concrete block, concrete

Notes a: Not on stabilised basecourse

b: Not if channeling of water flow expected due to soil wash which is common in third world environments

c: Not if urban drainage

d: Not if communal water systems present, since these lead to detergents washing on the road and erosion of the bitumen

e: Not at gradients above 10% if channeling of flow expected due to soil wash which is common in third world environment

CONCLUSIONS

The performance of bituminous surfacings on low volume roads is affected by environment, gradient, and maintenance. The choice of surfacing type must be made for each different set of conditions. The stresses on the surfacing can vary widely for the different conditions. The conditions in the urban and the third world environments are notably different to those in the rural first world environment. The selection of surfacing type should take all these factors into account to ensure good performance.

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