PRACTICAL ASPECTS OF LOW COST SEALING OF ROADS

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ABSTRACT

Many kilometres of earth and unsealed road in South Africa become impassable during the wet season cutting communities off from access to schools, clinics and job opportunities. In addition, the cost of operating vehicles on these roads during the remainder of the year is disproportionately high for the communities affected in relation to the service offered. Of equal or greater impact is the unsustainability of replacing the gravel lost from these roads under environmental and traffic influences.

Using conventional economic analysis and pavement design techniques, paving of these roads cannot be justified. However, when environmental and social benefits are considered, upgrading of many of these roads carrying traffic as low as 20 vehicles per day can be justified, particularly when large communities are affected.

Economic justification is, however, subject to the use of innovative pavement designs and the use of appropriate surfacing types that reduce the overall construction, maintenance and rehabilitation costs of the project. This paper describes some of the practical fundamentals of the design and construction of such roads.

INTRODUCTION

Almost three quarters of South Africa's proclaimed road network is unpaved as is the majority of the unproclaimed road network. This amounts to at least 500 000 km of unsealed roads in South Africa. When one considers that between 12 and about 25 mm of the gravel thickness is lost from the road annually under environmental and traffic actions it can be seen that about 30 to 60 million cubic metres (between 60 and 120 million tonnes) of gravel needs to be replaced annually to maintain the status quo.

In addition to the gravel loss, unsealed roads deteriorate significantly more rapidly than sealed roads and require constant maintenance, which is both costly and leads to unsafe traffic conditions on busy roads where the traffic interacts with graders, labour and temporary windrows. It should be noted that there are many unsealed roads in South Africa carrying in excess of 1000 vehicles per day.

Probably of greater significance, however, is the effect of unsealed roads becoming impassable during inclement weather. This can have a profound effect on the communities involved with loss of jobs, deterioration of crops and products that cannot be delivered and problems with access to schools and medical facilities.

The economic, social and environmental benefits of sealing many of the unsealed roads thus cannot be denied. Obviously it is not possible or even suggested that all unsealed roads be sealed. However, there are many thousands of rural access, urban and recreational roads that could be justifiably upgraded on the basis of these benefits.

This paper presents a review of some of the techniques and recent developments that make upgrading of unsealed roads to low volume sealed roads more financially viable. Although the discussion concentrates on the sealing of the roads, the importance of the underlying pavement structure is necessarily described.

BENEFITS OF SEALING

Sealing of roads can have direct economic, social and environmental benefits, providing solutions to some of the problems identified in the introduction. These include, among other benefits, improved access and safety of road users, environmental sustainability, reduced road user costs and sustainable creation of employment through small contractor maintenance contracts.

The economic benefits of sealing can be calculated using software such as Supersurf [10] or the Roads Economic Decision Model (RED) [8]. Experience has shown that the direct financial (ie, agency costs only) break-even point for sealing can be as low as 100 vehicles per day (vpd) while the economic (including road user costs) break-even point can be as low as 20 vpd [1]. Examples of such analyses for four specific sections of lightly trafficked road (traffic between 35 and 135 vpd) are summarised by Paige-Green et al [7].

It should be borne in mind that the social and environmental benefits of sealing low volume roads are very difficult to quantify. One way of handling these is to determine the value of these benefits that will result in an effective zero rate of return and then attempt to justify these values for the specific community and environment.

In order to improve the economic benefits of upgrading unsealed roads, the construction, maintenance and rehabilitation costs of the proposed pavement structure must be minimised.

PAVEMENT STRUCTURE

Conventional pavement designs are generally directed at high level of service, minimal maintenance structures requiring numerous layers of selected materials. Significant reductions in pavement cost for low volume roads can be effected by reducing the number of pavement layers and/or thicknesses, by using local materials and by using lower cost, more appropriate surfacing options [2]. Implementation of such measures, however, does not necessarily mean an increased risk of failure. They do require a greater degree of pavement engineering knowledge, experience and judgement and the careful application of fundamental pavement and material behaviour principles. Costly operations (eg, stabilization and the use of chip seals) should be substituted with less expensive alternatives, such as improved drainage and higher degrees of compaction.

It is, however, essential to understand the relationship between the road pavement structure and the surfacing. The relative strengths/stiffnesses of the pavement components (subgrade, selected layers, subbase and base course) all contribute to the provision of a balanced pavement structure that can support the applied loads without excessive elastic and/or plastic deformation of the pavement.

South Africa is in the enviable position that many of the in situ subgrade materials are relatively strong residual gravels, usually with California Bearing Ratio (CBR) strengths in excess of 15 per cent, and frequently in excess of 25 per cent. This eliminates the need for the importation of material for the lower layers in the pavement, and reshaping and compaction of these materials with the provision of an appropriate base layer is often all that is necessary to provide the required structural capacity.

This type of design must, however, follow conventional design principles, taking into account traffic types and volumes, local moisture regimes, topographic and pavement geometry constraints and local road user requirements. Philosophies in this respect are discussed in detail in the recently published SADC Guidelines for Low Volume Sealed Roads [2].

It should be noted that an important component in the design of conventional pavement structures is the minimisation of pavement deflections. Although not the rule, many of the lighter pavement structures can have relatively high deflections (in excess of 1.0 mm). This is not necessarily a problem, but the choice of surfacing would certainly be influenced, with more flexible types of bituminous seal being necessary [5].

More use should be made of quick, easy and robust equipment such as the Dynamic Cone Penetrometer (DCP) to characterise the existing "pavement" structure where existing unsealed roads have been in service for often lengthy periods. The upper 500 to 750 mm of such roads has usually been well compacted under the repeated traffic loads, particularly where there has been periodic agricultural, forestry or mining traffic. Construction of the new/upgraded road should minimise disruption of this existing structure.

Of equal importance is the quality of the base course construction. It is recommended that base courses on these types of road be compacted to refusal for the plant available and not to a nominal percentage of for instance AASHTO maximum dry density. Layer stiffnesses can be significantly increased by a small amount of additional compaction (one of the lower cost operations during construction) and other characteristics such as permeability and rutting potential are also decreased and improved respectively.

The finish of the base course is critical for many of the seals to be discussed in the following section. The thin single seals (eg, sand and slurry seals) are typically not more than 4 or 5 mm thick and thus the final surface of the base course needs to be cut to tolerances better than this. Any irregularities greater than the thickness of the seal will result in very thin or no surfacing in the crest areas which will rapidly wear through and result in the formation of potholes.

The practice of constructing the base (and sometimes priming it) and allowing traffic on it prior to sealing should not be permitted. It is better to construct a primer or single sand seal immediately and then follow up with the final seal as soon as practically possible.

The potential for large increases in traffic using a road immediately after upgrading must always be assessed. Many cases of low volume sealed roads upgraded from unsealed roads that have failed rapidly after construction have been noted. Particular attention should be paid to assessing the potential for attracting or generating extra traffic, particularly heavy vehicles, during the design stage. Where this likely, the pavement design should be modified accordingly. Large increases in light traffic are not a problem and, in fact, improve the economic justification for upgrading the road.

MOISTURE

There is irrefutable evidence that the dominant cause of failure in adequately designed roads results from excessive moisture in the pavement materials [2, 4]. Most well constructed and well maintained bituminous surfacings provide an effective barrier to the entry of moisture from above the pavement. Problems are thus related primarily to the ingress of water from alongside or below the pavement structure as a result of inefficient side drainage. Poorly constructed or maintained shoulders are often a primary cause of this.

The ingress of water from adjacent to the road can be controlled by ensuring that the road is provided with adequate side (table) drains with inverts at least 450 and preferably 750 mm below the crown of the road. These drains must be connected to regular mitre drains removing water well away from the pavement structure and must be regularly maintained.

Sealed shoulders are highly beneficial in "moving" the zone of moisture influence away from the effective outer wheel path of the pavement. However, many low volume sealed roads have reduced widths that remain adequate for the traffic and yet require the use of less material, reducing the pavement cost. Sealing of the shoulders typically provides the road user with a perception of a wider road and the shoulder then becomes part of the travelled carriageway.

One solution to this has been observed in Australia where no centre-line is provided on the road, but the shoulders are demarcated with solid painted lines. This certainly had the effect of "forcing" the traffic towards the centre of the road between the lines, but road safety experts were not happy with the principle, although no statistics supporting their concerns were available. On roads carrying less than 75 or 100 vpd, providing the correct signage and warnings can be expected to avoid problems in this regard.

The use of visual or textural differences between the carriageway and the shoulders (see following section) can also be implemented to reduce the movement of traffic on the shoulders.

PRIMING

There has been much debate regarding the requirement for primes on low volume roads. The application of a prime can increase the cost of constructing a nominally low-cost road significantly. However, the benefits of priming should not be underestimated. Only where roads are to be surfaced with seals such as graded aggregate seals that use low viscosity binders should the prime be omitted. Seals such as Otta seals that also tend to be thicker can be applied without a prime. It is recommended that where the bases are sandy or consist of absorbent materials (eg, some calcretes) they are primed to reduce the risk of too little bitumen being available for an effective seal.

It is also beneficial to make use of low viscosity primes that penetrate the surface of the base and effectively bond the top 10 to 20 mm of base. Experience has shown that this increases the strength of the upper portion of the base to a point that can resist shear failure or crushing under tyre contact pressures. On sandier materials, the prime also bonds the loose material together allowing a better bond between the base and the seal. Enrichment of the upper few centimetres of the base course using bitumen emulsion prior to final compaction and trimming can also be highly beneficial.

Investigation of a wide range of low volume sealed roads has indicated that where the prime has penetrated deep into the base (15 to 25 mm in many cases) the development of potholes from small deficiencies in the seal (stone loss, rim marks, etc) is greatly reduced and the rate of deterioration greatly retarded. Bitumen, of course, also reduces the potential for moisture movement into the layer.

SEAL OPTIONS

A wide range of seal options is available for consideration on low volume sealed roads. Each of these has particular advantages and disadvantages and will vary in cost. However, the final selection of an appropriate seal for any project must be based on the consideration of a number of factors, not necessarily related directly to the prevailing technical issues. These include:

Pavement structure

Natural environment

Social environment

Political environment

Construction techniques and plant availability

Maintenance capacity

Pavement structure

Where the pavement structure is thin or the subgrades are particularly weak, the pavement can be expected to have relatively high deflections. Surfacings applied to this type of pavement structure must be relatively flexible, thus excluding asphalt and stiffer surfacings such as slurries that are prone to rapid hardening and subsequent cracking. Graded aggregate seals are particularly flexible because of the low viscosity binders typically used and sand and chip seals can be "rejuvenated" periodically with light diluted emulsion sprays to maintain the flexibility of the binder.

Natural environment

In steep areas thin seals are unlikely to perform well. They can be severely affected by the flow of surface water over them: any weakness can be eroded and the formation of severe gulleys and erosion of the road base follows rapidly. On steep grades thin seals are prone to shoving under wheels leading to loss of bond with the base and stripping. Asphalt and/or concrete are the only suitable surfacings fro grades in excess of 12 or 16 per cent respectively [1]. In flat terrain, dispersion of water from the pavement structure can be difficult and this could lead to higher pavement deflections during the wet season, necessitating the use of more flexible seals.

The natural environment also includes the prevailing climatic regime. Precipitation needs to be considered in terms of water action and subsurface drainage. Pavement surface temperatures must be considered when selecting the appropriate binder types.

Social environment

Sealing of roads in specific social environments can be wrought with pitfalls. Communities often aspire to asphalt paved roads in order to feel that they are not being discriminated against. The use of local community labour for construction can alleviate this problem to some extent, but it is essential that there is active stakeholder involvement throughout the design and construction process.

Roads in rural and many urban areas often cater as play areas (perhaps this should be discouraged), pedestrian walkways and to other social needs. In these cases, surfacings that are not excessively rough (slurry, sand and Otta seals) should be employed. It is very uncomfortable for children playing on 16 mm (or larger) single seals and apparently difficult to walk in high heeled shoes on such surfaces.

In urban areas water that contains detergents is often discharged onto roads for removal by sidedrains. This water can have a serious effect on thin bituminous surfacings.

Political environment

The visual appearance of the road can have significant implications in the eyes of politicians, who like to be seen to be providing high quality pavements and not apparently low-cost solutions. This can be particularly important with seals such as Otta and sand seals, where although the final product is often indistinguishable by the untrained eye from asphalt, has a "settling-in period" during which the surface looks like a gravel road.

The perceived (usually incorrectly) increased risk of failure can also have serious political connotations. Politicians will not accept a structure that is considered likely to fail prematurely or require maintenance (eg, the second application of a sand seal) shortly after construction.

Construction techniques and plant availability

Depending on whether construction is planned to be executed using mostly mechanical plant, mostly labour or varying combinations of plant and labour, specific types of seal may be more or less suitable. Chip seals for instance are very unforgiving when stone or binder application rates are incorrect or inconsistent, whereas sand and Otta seals are less affected by these issues. Various documents are available that describe the suitability (and construction techniques) of different seal types for labour based construction [14,15].

Similarly, in remote areas or where emerging contractors without sophisticated resources (including old or poorly maintained plant such as chip spreaders and binder distributors) are contracted, the choice of seal can be severely affected.

Maintenance capacity

The thinner seals are obviously more prone to deterioration resulting from factors such as ageing, cracking and potholing unless adequately maintained. Many instances can be cited where thin seals have been almost totally lost after a couple of years as a result of insufficient maintenance. In cases where the maintenance capacity is poor, more durable surfacings, including asphalt or even concrete, must be considered to ensure sustainability of the road and preservation of the asset.

APPROPRIATE SEALS

Sand/grit seals

These seals consist of a tack coat of appropriate bituminous binder that is covered with a thin layer of relatively clean sand. Typically this material is obtained from rivers in granitic terrain but may be available in other areas depending on the geomeorphology and geology, eg residual quartzitic soils. The material should preferably have a maximum size of 6.7 mm and less than 2 or 3 per cent finer than 0.075 mm. Recent experience, however, has shown that sands with up to 20 per cent of material finer than 0.075 mm can be constructed using labour based techniques and perform well under light traffic.

Minimal processing is necessary to produce materials for such seals. Some times, scalping at 6.7 mm through a screen or grizzly is all that is necessary: in other cases (particularly for river sands), no processing is necessary. This type of seal uses a non-rational design, ie, the balance between the binder and aggregate is determined by “trial and error” by regularly returning excess sand to the road until no additional material adheres to the binder.

Slurry seal

Slurry seals have, probably deservedly, earned a reputation as performing poorly if the recommended gradings [9] are not strictly adhered to on conventional road rehabilitation projects. Experience has, however, shown that slurry seals constructed from a reasonably clean crusher dust, or even selected river sands, can prove successful as a first seal on roads carrying low traffic volumes (less than 75 vpd) particularly when the heavy vehicle count is low (less than 3 or 4 vpd).

The use of such materials may, however, require the use of specific emulsions (eg, cationic for river sands) and experience in the area will soon determine which materials, emulsions and relative proportions provide the best service. Slurry seals are most appropriate for relatively small areas and localised maintenance, but can be used effectively on labour based projects where mixing is done using concrete mixers. It is important, however, that the aggregates sources are uniform and a consistent mix ratio is employed to avoid the final product looking too much like a patchwork job.

Graded aggregate seals

These seals are characterised by using aggregate that is relatively widely graded with low viscosity binders, They consist of the generic type of seal (eg, Otta seal [3,12]) as well as various proprietary seals. Otta seals constructed with natural gravels (often just scalped at 19 mm) have performed particularly well in many countries. The proprietary seals usually make use of crushed aggregate.

Like sand seals, graded aggregate seals do not follow rational designs, with regular sweeping of the aggregate onto binder rich areas until a natural balance between the binder and aggregate is achieved. Many Otta seal projects that have been considered unsuccessful have resulted from insufficient aftercare and it is essential that this procedure is diligently followed.

There is a possibility that graded aggregate seals constructed during cold weather could bleed when the ambient temperatures increase, but problems resulting from this can usually be rectified by blinding the rich areas with fine material (less than 2 mm) and rolling heavily during hot weather.

Chip seals

Chip seals [11], particularly for small remote projects are expensive and require very careful design and construction to ensure that the balance between the binder and aggregate is correct. Any deficiencies in binder may result in the loss of stone, while excess binder results in excessive bleeding of the seal. It has been noted, however, that limited bleeding can often be beneficial [5] in terms of improving the impermeability, flexibility and durability of the seal.

Chip seals, however, make use of an essentially single sized, strong, crushed material, increasing the stone costs considerably. Recent work [6] has shown that it may be possible to use much weaker aggregates and possibly even screened natural gravels successfully for chip seals on low volume roads.

Asphalt

The use of asphalt surfacings is not common on low volume roads. They are expensive using highly processed materials and high bitumen contents and, being relatively stiff, require strong pavement structures. There is no doubt, however, that on steep grades (12 – 16 per cent) and under harsh social environments in urban areas, they last much longer than any other types of seal and can thus prove cost-effective in the long term [1]. No comparison between the performance and life-cycle costs of asphalt and, say a double Otta seal has been carried out under these conditions. The minimum thickness recommended is 25 mm.

Concrete

The use of concrete as a seal cannot be excluded. Although not discussed in this paper, there can be many situations where concrete can provide the only practical or economic solution, eg, very steep slopes, weak subgrades (careful design usually using reinforcement is necessary in this situation), poor drainage conditions, etc.

PERFORMANCE AND LIFE

The performance and lives of different seals are very difficult to compare. Many factors including, among others, location, pavement structure, environment, maintenance capacity and traffic affect the lives of seals. Over the years, however, various estimates of expected life have been made (after [1,2,12,13]). These are summarised in Table 1.

Typical lives of various surfacing types (after [1,2,12,13])

Surfacing type	Typical surfacing life (years)
Single chip seal	3 to 6
Double chip seal	6 to 10
Otta seal + sand	8 to 10
Double Otta seal	10 to 14
Slurry seal	2 to 6
Single sand seal	2 to 4
Double sand seal	4 to 9
Asphalt	8 to 14

The estimated lives of the seal used in any economic analysis affect the result significantly and realistic expectations for any project need to be used in such analyses. It should also be noted that frequent resealing of roads that have lines and markings painted on them results in expensive repainting. Such aspects need also be considered in the overall life-cycle cost analyses. Omission of lines can have significant cost savings.

COSTS

Similarly to the surfacing lives, the costs of different seals can vary dramatically, depending on location, degree of competitive bidding, material availability, binder type and haulage requirements, etc. However, various relative costs have been proposed over the years (after [1,2,12,13]) and these are summarised in Table 2.

Table 1: Approximate relative costs of various seals (after [1,2,12,13])

Seal type	Relative cost*	
	With prime	Without prime
Sand	0.56	N/A
Slurry	0.85	N/A
Single Otta & Sand	1.00	0.75
Double Sand	0.90	0.70
Double Otta	1	0.90

Single chip seal	0.56	0.58
Double chip seal agg/agg	1	N/A
Single chip + sand seal	0.90	0.70
Cape seal	1.20	0.60
Asphalt	2.21	0.89

* cost of double 13.2/6.7 mm chip seal with prime is taken as unity

N/A – the use of these seals without prime is not recommended

agg – crushed stone aggregate

A relatively wide range of costs is noted. It is important to consider that although the cost of asphalt, for instance is nearly four times the cost of the cheapest seals, the life could be between 4 and 7 times that of these seals. This involves a considerably higher construction cost, but may often show benefits in terms of maintenance and rehabilitation costs. Although this table indicates no difference between the cost of sand and single seals, location can cause a significant difference. The aggregate for traditional single seals must be crushed and screened requiring proximity to an appropriate plant whereas the sand for sand seals can usually be extracted from a river bed at minimal cost. In urban areas, therefore, chip seals may be competitive with sand seals but in rural areas, sand seals can be considerably cheaper.

MODIFIED BINDERS

Although modified binders have a significant price premium, their performance in terms of improved durability and flexibility may often make them more cost effective in the long term. Little information regarding the effect of using modified binders on the estimated seal lives shown in Table 1 is available, but it is expected that the upper limits identified in the table are likely where modified binders are appropriate to the seal, ie, they have not been used and are unlikely to perform adequately with Otta seals.

THE FUTURE

The vast network of roads that needs to be sealed in order to provide the expected level of service to road users (in terms of accessibility and road user costs) and to avoid excessive environmental degradation cannot be upgraded using conventional pavement design techniques and designs. Innovations in this regard are essential and it is important that moves in this direction are initiated as soon as possible in order to develop a performance record for these innovations.

This can be achieved by incorporating short trial sections using innovative designs, materials and construction techniques on all low volume road projects. The costs and performance need to be carefully monitored and a data base developed that can be referred to when carrying out such designs and cost/benefit analyses.

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