PROJECT REPORT 91

AVOIDING SALT DAMAGE TO BITUMINOUS SURFACINGS: RESULTS FROM A ROAD TRIAL IN BOTSWANA

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Subsector: Geoscience
Theme: Improve understanding of the properties of engineering materials specific to developing countries
Project title: Naturally occurring materials
Project reference: R5603

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Overseas Centre, TRL, 1994
ISSN 0968-4093
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EXECUTIVE SUMMARY

Damage to bituminous surfacings, caused by the upward migration and crystallisation of soluble salts present in the pavement materials or foundation, has been widely reported. The phenomenon is restricted to warm arid or semi-arid climates where evaporation of moisture exceeds precipitation. Small salt contents of the order of 0.3% by mass of the construction material apparently cause the damage, which is manifested by blistering or doming of the surfacing with a concentration of crystallised salt in the vicinity of the disruption. Thin surfacings such as prime coats and surface dressings are particularly susceptible and, since the use of these surfacings is common on low volume roads, it is important to establish the key variables that cause the damage.

Existing specifications to avoid salt damage that have been developed in South Africa, the Middle East and Australia, vary in terms of salt limits, salt types and methods used to determine salt content. This probably reflects different local experience but it is considered that a more universal approach is needed.

In collaboration with the School of Civil Engineering of Birmingham University and the Botswana Ministry of Works & Communications, a programme of research was carried out, preceded by laboratory work and followed by a field trial. The results of the field trial form the subject of this report.

The laboratory work found that several factors influenced the potential for salt damage to bituminous surfacings besides the most obvious one of salt content. They were: the type of prime coat, the salinity of the groundwater, the elapsed time before the surfaces were primed and the elapsed time before they were surface dressed. The time before the onset of damage differed depending whether single or double surface dressings were applied. The main purpose of the field trial was to confirm the laboratory findings and hence to define suitable design criteria so that bituminous surfacings would resist salt damage better during construction and whilst in service.

The key variables included in the field trial were the salt content of the construction materials and of the compaction water. Trial sections were constructed on both non-saline and saline subgrades to determine what effect the subgrade would have. Other variables considered were: the type of prime coat applied to the roadbase; different time delays between the completion of construction and the application of the prime; different time delays between the completion of priming and application of the surface dressing, including situations where no prime at all was used; single and double surface dressings (in line with normal construction practice, where they are used for the road shoulders and carriageway respectively). The field trial was constructed on an existing gravel road which was eventually closed after the construction of an adjacent new road: thus, the trial sections received normal traffic for a time but eventually no traffic at all. This permitted another variable, i.e. traffic, to be taken into account. (The situation of no traffic might be more appropriate to airfields). It was expected that damage would be inevitable where saline subgrades occurred. In these circumstances impermeable membranes were placed between the roadbase and the saline subgrade to determine their efficacy in preventing salt damage.

The field trial was monitored for four years during which visual inspection coupled with determination of salt content of the roadbases and subgrades was carried out at regular intervals. For the visual inspection a scale of 0 to 5 was employed based on increasing severity of damage to the surfacings. Because of the large numbers of samples involved, the electrical conductivity of the samples was determined using a standard procedure. The salt content was then calculated from a (previously determined) correlation between the electrical conductivity and Total Soluble Salt (TSS).

The results of the field trial confirmed that the bituminous prime coats were damaged by salt contents in excess of 0.3% TSS unless they were surface dressed quickly, i.e. within three days. A greater delay to priming increased the risk of damage because the salt accumulated in the upper levels of the roadbase.

In contrast, the surface dressings were much more resistant to salt attack. Both single and double surface dressings, constructed on the non-saline subgrade, were not damaged by salt even when the roadbases contained up to 1.0% TSS. The withdrawal of traffic from the site has not affected the integrity of the double surface dressing but the single surface dressed road shoulders have showed signs of damage after four years.

The surface dressings applied to roadbases constructed on a saline subgrade were not damaged whilst being trafficked but, once the traffic was withdrawn, rapidly became damaged by salt crystallisation. The damage affected all trial roadbase sections, even those containing no salt to begin with, due to the (comparatively rapid) rise of salt from the saline fill through the roadbase and its accumulation beneath the surfacing. It was found that the inclusion of an impervious membrane, such as polyethylene sheet, within the road structure arrested the rise of saline moisture from the subgrade and protected the surfacing from salt damage.

The results from this field trial and other recent research indicate that revision of the existing Botswana specifications, where it is stipulated that roadbase and sub-base salt contents should not exceed 0.2% and 0.4% TSS respectively, may be appropriate for non-saline subgrades; however, where saline subgrades occur, other preventative measures must be used. As a result of its success in the trial, polyethylene sheet was used for the lengths of the new road that crossed the salt pan.
AVOIDING SALT DAMAGE TO BITUMINOUS SURFACINGS: RESULTS FROM A ROAD TRIAL IN BOTSWANA

ABSTRACT

The Paper discusses the results of research undertaken in Botswana to provide design criteria to avoid damage inflicted on thin bituminous surfaces by soluble salt. The damage, characteristic of warm arid or semi-arid regions of the World, occurs when the salt crystallizes within the pavement, physically disrupting the bituminous surfacing and causing premature deterioration of the road. The criteria were derived from observations made on a road trial constructed in May 1990 in northern Botswana where the salt levels at which damage occurred and the nature and development of the damage were investigated. Some preventative measures were incorporated in the trials to determine their efficacy in avoiding damage. The results from the trials have enabled a revision of the current Botswana road design standards (with respect to salt limits in pavement materials) to be proposed.

1. INTRODUCTION

During recent years the Government of Botswana has been undertaking an intensive programme of improving earth and gravel roads to bituminous standard. In the Kalahari region this work mainly involves the application of prime coats and surface dressing to natural gravel roadbases. Whilst the presence of salt is beneficial to earth and gravel roads because it retains water and helps bind the material during the prolonged dry season, comparatively thin (< 50mm) bituminous coatings can be damaged by soluble salts present in the pavement materials, including the compaction water, subgrade or groundwater. In 1990 severe salt damage occurred to the airstrip serving the Sua Pan salt factory, see Plate 1. The airstrip consisted of a Cape seal (a surface dressing with a slurry seal cover) laid on a calcrete roadbase where saline water was apparently used for compaction. The airstrip was constructed on a saline subgrade. Within two months the surface had become extensively blistered, necessitating remedial measures (rolling) to be carried out regularly afterwards.

Soluble salt is defined (Netterberg & Maton, 1975) as "basically those minerals that are the most soluble, notably salts of magnesium and sodium". Gypsum (calcium sulphate), an abundant salt, is only slightly soluble and does not cause damage. The damage is actually caused by the upward movement and crystallization of the salt in the top of the pavement, whereby the bituminous material is lifted and its adhesion to the roadbase destroyed. The disruption is essentially a

Plate 1. Sua Pan Airstrip (March 1990). Typical damage to surfacing, three months after construction.
physical process; no chemical effect is involved. Obika et
al. (1989) reviewed the reported incidence of salt damage and
concluded that it was restricted to the warm arid and
semi-arid regions of the World with large diurnal ranges of
temperature and relative humidity. These climatic
conditions are typical in Botswana and with the extensive
occurrence of salt pans and saline groundwater, there is
clear potential for salt damage.

The content of soluble salt required to cause damage is
low. The current specifications for Botswana (1980) quote
maxima of 0.2% and 0.4% Total Soluble Salt (TSS) for
the roadbase and sub-base respectively. These limits
were derived by Netterberg et al (in Weinert, 1980) but
numerous workers since, e.g. Horta (1985), Overby
(1983), Spottiswoode and Graham, (1982), Januszke &
Booth, (1992), and more recently Netterberg (Pers.
Comm: re: Swartklip trial, 1986), report on instances
where much higher salt contents in the road pavement
materials have not resulted in damage to the bituminous
surfacing. The specifications would therefore appear to
need revision.

The research was a collaborative venture between the
Transport Research Laboratory (TRL), the School of Civil
Engineering at the University of Birmingham and the
Ministry of Works, Botswana. A programme of laboratory
work (Obika, 1991) preceded a field trial which was
carried out during the construction of a new road from
Maun to Nata, see Fig 1. The field trial was constructed
on part of the original gravel-surfaced road. The new road
followed a close but separate alignment to the old road
and skirted the northern fringe of the Makgadigadi Pans,
a vast inland draining depression characterised by high
salt levels. A notable feature of the region is the natural
occurrence of two very soluble salts, sodium bicarbonate
and sodium chloride, combined together in the natural
materials.

2. OBJECTIVES

The laboratory work carried out in advance of the field
work indicated that the prime coats were particularly
sensitive to low contents of salt in the pavement materi-
als. The surface dressings, however, were resistant to
much higher levels of salt for the limited duration of
the experiment. It was to confirm these relationships for the
conditions in Botswana that the field trial was con-
structed. In so doing, it was hoped to define suitable
design criteria for roads with thin bituminous surfacings,
i.e. prime coats and surface dressings, in order that they
would better resist damage from soluble salts. At the
same time the opportunity was taken to investigate the
effectiveness of several preventative treatments.

3. EXPERIMENTAL DESIGN

The key variables influencing damage to the bituminous
surfacings identified in the laboratory work were, perhaps

obviously, the salt content of the roadbase and the water
used in the compaction of the roadbase. A further source
of salt, very important in the longer term, is that derived
from the lower levels of the pavement. Other variables
considered were the type of prime coat applied to the
roadbase and the time delay between the completion of
the construction of the roadbase and the application of
the prime. The further delay between the completion of
priming and the application of the surface dressing was
also considered important and included in the field trial,
as were single and double surface dressings. Although
the thickness of the bituminous material influences
whether or not damage occurs, it was not possible to
include this variable without unduly complicating the
experimental matrix.

A location for the field trial was chosen near the village of
Zoroga, 50km west of Nata, in northern Botswana, see
Fig 2. Two separate sites 2.5 km distant from one
another on the original gravel road were selected. At Site
1 the road was constructed on a hard calcrite roadbed
but at Site 2 the road had been built up with sand above
the level of the surrounding salt pan. Thus the road was
built on a non-saline subgrade at Site 1 and on a saline
subgrade at Site 2. It was found that remote sensing
techniques were very useful in revealing the spatial
distribution of the non-saline and saline terrain (Stone,

At each site, six trial roadbase sections were constructed,
plus an additional control section at Site 1. The
roadbases consisted of calcrite natural gravel (a partly
indurated material derived by cementation of the Kalahari
sand) designed to contain 0.07%, 0.60% and 1.34% TSS;
these salt contents span the current Botswana specifica-
tions. Water of two different salinities was used in the
compaction of the calcrite; thus roadbases with six
different salt levels were obtained. Trial roadbase
sections were constructed at the two sites, thus giving
twelve sections. The control, Section 3, consisted of non-
saline calcrite compacted with non-saline water. The
design is shown in Fig 3.

Each trial section was subdivided into subsections
depending on the type of prime used and the delay
between the construction of the section and the applica-
tion of the prime. Also, the effect of different delays
between the priming and surface dressing was evaluated
by staggering the application of the first surface dressing
in two stages. The second surface dressing was applied
universally. The road carriageway (6m wide) was double
surface dressed and the shoulders (1.5m wide) were
single surface dressed, according to normal construction
practice.

To assess the effectiveness of preventative measures,
two impermeable membranes, one comprising a thick
bitumen layer and the other a polyethylene sheet, were
incorporated at the bottom of the roadbase at Subsec-
tions 6 and 7 of Section 8.

The field trial was trafficked for 18 months, after which
traffic was diverted on to the new road which had been
completed by this time. Thereafter the trial sections
Fig. 1 Republic of Botswana road network (at March 1994)
received no traffic. This enabled the effects of no traffic on the condition of the sections to be assessed: knowledge of these effects would perhaps be useful in the case of airfields.

4. CONSTRUCTION

Sites 1 and 2 were each about 130m long with individual sections varying from 12 to 25m in length. The non-saline calcrete was obtained from a nearby borrow pit and the saline calcrete was obtained from the gravel-wearing course of the old road where it crossed the salt pan. An intermediate saline calcrete was prepared by mixing the non-saline and saline calcrites. Fresh and saline water (for compaction) were obtained from local sources.

Grading and compaction data for the calcrete roadbases and sand sub-bases are shown in Fig 4. The non-saline calcrete contained much oversized material which had to be removed by hand.

The wearing course gravel was stripped from the two sites over a length of 400m and thickness of 300mm. At Site 1, 150mm of non-saline sand was laid in order to provide a level surface on which to construct the trial roadbases. This was not necessary at Site 2 but the embankment sand had to be reshaped.

Three calcrete stockpiles were prepared in the borrow pit, i.e. non-saline, intermediate and saline calcrites from which material was drawn as necessary to form the individual sections. The in-situ moisture content of the calcrites was about 7%, enabling fresh, brackish or saline water to be added as required to bring the calcrete to the optimum moisture content for compaction. The water was mixed into the calcrites by grader.
The prepared calcrite was transported to the trial site, placed and shaped using a grader. This required considerable skill by the grader-operator due to the short length of the individual sections. Transition zones of 3m length were established between each section to avoid contamination of one section with another. A 15 tonne vibrating roller was used to compact the calcrite; each section received two passes without vibration followed by four passes with vibration. The small size of the sections made it difficult for the compactors to work effectively and somewhat variable densities were obtained. However, roadbase strengths were adequate to prevent deformation of the surfacing by traffic.

Each section was subdivided into subsections of 3m length and either cutback or emulsion prime applied. The cutback prime was MC30, a low viscosity medium-curing type, and the emulsion was a medium-setting cationic type. Individual sections were separated from one another by the transition zones mentioned above.

The primes were sprayed on the roadbases, which had been previously swept and sprinkled with water to suppress dust, in 3 metre wide strips across the whole road width, using a hand-operated, motorised lance. The achieved prime application rate ranged from 0.7 to 1.4 litres/sq m (equivalent to 0.5 to 0.9 litres/sq m residual bitumen). Each section also included a subsection with no prime coat.

A 150/200 penetration grade bitumen was used for the binder for the first surface dressing at an average application rate of 1.5 litres per sq m. A quick-setting cationic bitumen emulsion (KRS 60) was used as the second surface dressing at a residual bitumen application rate of 1.2 to 1.3 litres per sq m. Nominal aggregate sizes were 19mm and 9.5mm with average least dimensions of 10mm and 4.5mm respectively. Plate 2 shows the various stages of the construction.

The impermeable membranes were applied in Section 8 of Site 2. In subsection 6 a 0.55mm thick clear polyethylene sheet was laid on the saline embankment sand below the roadbase and in Subsection 7 bitumen emulsion at a residual bitumen application rate of 2.5 litres/sq m was similarly applied. The emulsion was the same as that used for the prime coat.
Fig. 4  Salt damage road trials: particle size distribution of trial bases and sub-bases
Soon after the second surface dressing had been applied the sites were opened to traffic, estimated to be 150 vehicles per day per lane, of which 40% were commercial (i.e. with unladen weight of at least 1.5 tonnes). After 18 months the traffic was diverted on to the new road; the trial sections then received no traffic.

5. MEASUREMENT TECHNIQUES

The resistance of the bituminous surfacing to salt damage, whether prime coat or surface dressing, was assessed by visual observation. During the preceding laboratory work a "severity rating" was developed for use in the field. It is summarised in Table 1 below and is somewhat subjective owing to the progressive nature of the damage.

### TABLE 1

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description of damage</th>
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<tr>
<td>0</td>
<td>No damage to surface</td>
</tr>
<tr>
<td>1</td>
<td>&lt; 10% of surface damaged</td>
</tr>
<tr>
<td>2</td>
<td>11 to 25% of surface damaged</td>
</tr>
<tr>
<td>3</td>
<td>26 to 50% of surface damaged</td>
</tr>
<tr>
<td>4</td>
<td>51 to 75% of surface damaged</td>
</tr>
<tr>
<td>5</td>
<td>&gt; 75% of surface damaged</td>
</tr>
</tbody>
</table>

Together with the visual evaluation, the trial roadbases were sampled for determination of soluble salt content, discussed in more detail below. Generally, three samples were taken at each sampling point, representing depths of 0 to 50mm, 50 to 100mm and 100 to 150mm of the roadbase. From the standpoint of damage to the bituminous surfacing, the 0 to 50mm sample was of most interest. Previous work had shown that whilst it could be assumed that the salt was evenly distributed in the roadbase at the time of construction, it eventually became concentrated in the upper part of the roadbase due to the movement of moisture through the roadbase layer. However, it was important to check if the concentration in the top of the roadbase was matched by a depletion in the bottom.

5.1 DETERMINATION OF SALT CONTENT

Most of the analytical techniques available to determine salt contents are time-consuming and some require a considerable degree of skill. For this reason another method has been developed to overcome these difficulties whereby the electrical conductivity (EC) of an aqueous solution of the material is measured, using a standardised procedure, and the values related to the Total Soluble Salt of the sample. The relationship between EC and salt content is complex and although it is not possible to obtain a correlation on a global basis it has been proposed on a regional basis, e.g. Doormamp et al (1986) in the Middle East.
The standardised method of determination of EC is based on the US Bureau of Soils paste method, subsequently adapted by the Southern African Roads Authorities and described in Method A21T of TMH 1:1986. However, for this project, because of the large number of samples, a quicker and more field-adaptable method was used. It is based on a method reported by Kamalldin et al in a UNESCO publication. A summary of the method is given in Appendix A. The TMH method and the UNESCO method require the preparation of solutions of quite different salt concentration (containing about 28% water in the former and 67% water in the latter). Therefore, it was necessary to correlate both methods. It was found that the EC determined by the TMH method gave results 30% higher than the UNESCO method. This relationship was determined after testing 63 samples with conductivities ranging between 0.5 and 15 mS/cm. The correlation had an R² value of 99% and a standard error of estimation of 0.38, thus indicating a systematic difference.

To establish the correlation between the UNESCO EC and mass percentage TSS, measurements of each were determined on 70 samples. The TSS was measured according to the method given in BS 1377: Part 3:1990 and there is no doubt that it is long-winded because of the care required to avoid contamination by atmospheric moisture when determining very small masses of salt (which is itself hygroscopic). Each TSS test took the best part of a working day. The correlation established, specific to the Nata-Maun materials was:

\[
TSS = 0.16EC + 0.04
\]

A correlation coefficient of 0.85 and standard error of estimate of 0.27 was obtained for this relationship, for a range of percentage TSS of 0 to 1.5. The EC was measured in millisiemens per cm (a Siemens is the reciprocal of the electrical resistance in ohms) at 25°C. All determinations were carried out on the fraction of the samples passing 20mm only, corresponding to about 75% by mass of the borrow pit material: it is generally recognised that the major proportion of the salt is contained in the fine-grained material.

It was of interest to determine the nature of the soluble salt and it was confirmed by further chemical analysis that it comprised a combination of sodium chloride and sodium bicarbonate (nahcolite), with roughly 67% of the former and 33% of the latter.

6. ROAD TRIAL RESULTS

6.1 CLIMATE

Rapid evaporation, promoted by high temperatures and wind speeds, together with low precipitation are key elements in the salt damage process. Also, atmospheric humidity is fundamental to crystal growth because crystallisation will occur only when ambient relative humidity is lower than the equilibrium relative humidity of the saturated salt solution (Cooke et al, 1993). For these reasons, the salt damage phenomenon is not encountered in cooler or wetter climates. An important factor in the preliminary investigations was therefore the acquisition and assessment of climatic data. Meteorological data for 1991 for Maun, Francistown and Gaborone indicated that during the summer months (November through April) the typical daily temperature ranged from 40 to 15°C (over 24 hours) and relative humidity from 40 to 90%; in the winter months conditions were generally much cooler (25 to 5°C) and drier with the relative humidity below 75% for most of the day.

Data collected at the trial site during construction (April/May 1990) and during one of the visits afterwards (October 1991) are shown in Fig 5. They confirmed the collected data and also indicated high wind speeds.

The equilibrium relative humidity of sodium chloride, the main salt type, is 76%. Both summer and winter conditions therefore favour the precipitation of salts; possibly the higher temperatures and greater wind speeds of summer are more favourable since they increase the rate of evaporation.

The previous research carried out in the West Indies (Obika et al, 1991) and elsewhere (Horta, 1985) found that the damage inflicted on the bituminous coats was principally caused by the preferential growth of a fibrous crystal form of NaCl or salt "whisker". The growth of elongate crystals such as these is focused along their long axis. They are therefore potentially more disruptive than the more common cubic type.

6.2 PERMEABILITY

Evaporation is an essential process in the salt crystallization cycle and the permeability of the roadbases, primed and unprimed, was estimated using a simple field method whereby the time taken for a column of water to dissipate through a known area was measured. It was found that, for reasonably fresh materials (the permeability tends to increase with the age of the bituminous coating), the unprimed base was approximately ten times more permeable than the primed bases, and the cutback-primed base was slightly more permeable than the emulsion-primed base. Both single and double surface dressings were virtually impermeable using this method.

6.3 DAMAGE TO PRIME COATS

6.3.1 Visual Evaluation

Reference is made to Tables 2 and 3 below which summarise the findings of the investigation into the use of different prime types and different delays to application of prime for Sites 1 (non-saline subgrade) and 2 (saline subgrade) respectively. Results for only some of the sections of Sites 1 and 2 are shown; a complete set of results is given in Appendix B. The initial salinities refer to the whole of the roadbase and for these the percentage TSS was determined directly, whereas in subsequent samples the percentage TSS was derived from the EC.
Fig. 5 Botswana: climatic data
TABLE 2

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<td>1 2 3 4 5 6 7 8</td>
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<td>Prime Type</td>
<td>C C C E E</td>
<td>N C C E C E</td>
<td>N C C E E</td>
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<tr>
<td>Initial Salinity of roadbase, %TSS</td>
<td>0.70</td>
<td>0.62</td>
<td>1.16</td>
</tr>
<tr>
<td>Time (days) bet cons. &amp; priming</td>
<td>4 6 1 4 5 7 1 4</td>
<td>- 1 2 3 5 1 2 4 1 3</td>
<td>- 2 2 5 3 1 2 1</td>
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<tr>
<td>Pre-priming Salinity, % TSS, (0 to 50mm)</td>
<td>0.7 to 1.2</td>
<td>0.7 to 1.3</td>
<td>1.3 to 2.1</td>
</tr>
<tr>
<td>Severity Rating</td>
<td>3 3 0 2 3 1</td>
<td>- 2 2 2 1 0 2 1</td>
<td>- 3 3 4 2 3 2</td>
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TABLE 3

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<td>1 2 3 4 5 6 7 8</td>
<td>1 2 3 4 5 6 7</td>
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<td>Prime Type</td>
<td>E C C E E</td>
<td>E C N C C E</td>
<td>C C N C E E</td>
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<tr>
<td>Initial Salinity of roadbase, %TSS</td>
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<td>0.60</td>
<td>1.32</td>
</tr>
<tr>
<td>Time (days) bet cons. &amp; priming</td>
<td>9 9 1 4 9 1 4 1 4 14</td>
<td>3 3 - 6 1 2 1 1 1 1</td>
<td>1 2 - 7 2 7 1 2</td>
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<tr>
<td>Pre-priming Salinity, % TSS, (0 to 50mm)</td>
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<td>0.7 to 1.3</td>
<td>1.5 to 1.9</td>
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<tr>
<td>Severity Rating</td>
<td>0 0 0 0 0 0</td>
<td>3 4 3 1 4 3 1 3</td>
<td>4 4 - 5 4 5 1</td>
</tr>
</tbody>
</table>

Notes:  
C = Cutback Prime  
E = Emulsion Prime  
N = No Prime  
- = Not applicable

Most bituminous prime coats became salt-damaged to some extent: the only exceptions were those applied to the non-saline roadway sections (nos. 1, 3 and 8) and the emulsion primed subsections of the slightly saline roadway section (no 9). Increasing delay to priming did not necessarily result in greater damage to the prime, a surprising result considering the increased accumulation of salt beneath the prime surface (see below).

Damage to the primes usually occurred within a few days of their application, see Plate 3. The cutback primes became discoloured to brown, followed by a progressive development of a crumbly or spongy texture with the eventual separation of the prime from the roadbase. Small blisters appeared on the emulsion primes which became larger and more numerous with increased salt and/or increased time delays. The underside of these blisters were coated with salt crystals, in the characteristic whisker-type form.

Although the less permeable emulsion prime was more resistant to salt attack than the cutback prime it did not soak into the roadbase and bind it for subsequent surfacing, rather it formed a skin on the surface. The cutback prime was also easier to treat after it had been damaged by salt. Brooming was used to restore a lightly damaged surface, leaving the roughened surface underneath as a key on to which the surface dressing bitumen could be applied. The emulsion, however, was delicate and prone to detachment from the surface of the base, especially in the warmer parts of the day.

In the subsections where surface dressing bitumen was applied without priming, it was observed that there was poor adhesion of the surface dressing to the roadbase. However, these subsections remained undamaged throughout the duration of the trial.

6.3.2 Salt Content of Roadbases

Significant increases in salinity prior to priming were measured in the upper 50mm of the roadbases of all sections, compared to their construction salinity. Fig 6 shows the increases graphically. The greater the initial roadbase salinity, the greater the rate of increase of salinity. The following relationship has been established.
Plate 3. Site 2, Section 12: left-hand arrow shows typical damage to emulsion prime and right-hand arrow to cutback prime, 7 days after application (April 1990).

**Fig. 6** Salt trends in top 50mm of road bases before priming
(using 70 data points), having a correlation coefficient (R²) value of 94% and standard error of 1.0:

\[ E_t = -0.66 + 1.13E_i + 0.53 (T \log_{10} E_i) + 0.14T \]

where:

- \( E_t \) = the salinity at time \( t \), for a range of 1.0 to 20.0 mS/cm
- \( E_i \) = the initial salinity, for a range of 0.0 to 10 mS/cm
- \( T \) = time, in days, for a range of 0 to 14 days.

The relationship is applicable over the range of variable values quoted and for the site conditions prevailing, i.e. climate, construction conditions and material characteristics. It is therefore not generally applicable.

The increasing concentration of salt at the surface of the roadbases of Site 1 (non-saline subgrade) generally resulted in salt depletion at the bottom. The same trend was initially observed for the roadbases constructed at Site 2 (saline subgrade) but, after a longer period (about 7 days), salt increases at the bottom of the roadbases were observed due presumably to replenishment from the subgrade. These trends are shown graphically in Fig 7. It is estimated that the rate of salt rise was about 5mm per day.

Samples taken after application of the prime coats but before surface dressing (maximum interval, 17 days) show further changes, indicated in Appendix C. The cutback-primed roadbases show continued but less rapid increases in salinity whereas the emulsion-primed roadbases show either little change or only slight decreases in salinity, especially at Site 2. This observation confirms that the emulsion prime produces a more efficient seal than the cutback prime.

Although early priming generally resulted in reducing the rate of salt increase in the roadbase, it did not ultimately prevent damage to the prime coats. This primarily depended on the initial salt content: if it was greater than 3.3% TSS then the prime coat was susceptible to damage unless surface dressed within a short time period (approximately three days).

### 6.4 DAMAGE TO SURFACE DRESSING

#### 6.4.1 Visual Evaluation

Visits to evaluate the condition of the surface dressing were made at six monthly intervals for the first two years, then at yearly intervals.

The double sealed carriageway of both trial sites remained in good condition whilst they were being trafficked, although most of the smaller chippings of the second seal coat were lost, either because of an underapplication of binder or because the sections were trafficked too early. Once the traffic was diverted on to the new road however, all the double surface dressed sections at Site 2 (saline subgrade) became progressively salt damaged, except for the subsection underlain by the polyethylene sheet, see Plate 5 and Plate 6. No damage attributable to salt had occurred to the carriageway of Site 1 (non-saline subgrade) by March 1994, the latest visit, see Plate 7.

The untrafficked, single sealed road shoulders at Site 2 showed salt damage in most sections (salt-filled blisters and domes) within six months, especially at the junction of the road shoulders and carriageway, see Plate 4. Eventually, lenses of salt up to 1 cm thick were observed at the top of the roadbase. At Site 1 only minor damage possibly attributable to salt has occurred in the shoulders.

Staggered delays, with a maximum difference of 14 days, between the application of prime coats and surface dressing were incorporated in the trial design. However, there has been no significant effect on the surface dressing in the four years since it was applied.

#### 6.4.2 Salt Contents of Roadbases

The salt levels of the upper 50mm of the roadbases under the carriageway where the salt concentrated are shown in Fig 8. The values showed considerable variation, especially where the initial salt content was high, but the main trends are summarised below:

i) Salt levels in the roadbases constructed on the non-saline subgrade (Site 1) have generally undergone little change since the application of the surface dressing; this includes the control, Section 3 (not shown in Fig 8).

ii) Salt levels in the roadbases constructed on the saline subgrade (Site 2) have generally increased, except for Sections 12 and 13 where there is no increase.

iii) The polyethylene sheet placed at the bottom of the roadbase in Subsection 8/6 had, up to the fourth year of observation, resisted the upward movement of salt from the saline fill. Part of it was deliberately exposed and visually it was still in good condition after four years. In contrast, the bitumen layer laid at a similar level in the adjacent Subsection 8/7 had not resisted the upward rise of salt, probably because it was punctured during construction.

iv) The difference in damage between the sections of Site 1 and Site 2 is not reflected in the salt levels. The salt contents of the most saline sections of Site 1, nos. 6 & 7, are about 1% TSS, only slightly lower than those of Site 2, Sections 8 & 9, which suffered damage soon after trafficking ceased.

Results for the road shoulders are omitted because of the physical disruption of the single seal by salt blisters at an early stage of the trial.

#### 6.4.3 Moisture Movements in the Pavement

The additional salt that has accumulated in the trial roadbases constructed on the saline subgrade has clearly been transported in rising moisture. The roadbed underlying Site 2 comprises saline sand and silt and
Fig. 7 Salt trends in the road bases prior to priming.
Fig. 7 (continued)
periodically in the rainy season (summer) it is flooded, thus enabling saline moisture to be drawn through to the road surface. The water table is not far below the ground surface: a local salt making industry 2 km south of the trial site pumps brine containing 11% TSS from a depth of about 10m.

It was mentioned earlier that the application of a bituminous coating reduced the rate of upward movement of salt-laden moisture from the subgrade and below. The gradual increase in salt levels of the roadbases at Site 2 (constructed on the saline subgrade) confirms that in the longer term in these climates salt accumulation will still occur. Salt rise beneath impermeable pavements has been noted by other authors, e.g. Nettetberg (15), Tomlinson (16), and Horta (5). It is possible that the large temperature gradients from the ground surface to a few cm below, shown in Fig 5, influence the speed of moisture rise in the soil.

7. DISCUSSION

The results from the field trial have confirmed the observations from the laboratory work in that the surface dressings are significantly more resistant to salt damage than the prime coats. The work of other researchers also indicates this and it would therefore appear reasonable to examine the current Botswana specifications (maxima of 0.2% TSS and 0.4% TSS in roadbase and sub-base respectively) to determine whether they are still valid.

7.1 PRIME COATS

It was confirmed that bituminous prime coats are very vulnerable to salt attack. The results showed that they were affected at very low salt levels, of the order of 0.2% to 0.3% TSS, (salt content in the whole of the roadbase) with the cutback primes being less resistant than the emulsion primes. At salt levels greater than the above the onset of damage was quicker, usually within two days, and more severe in terms of the degree of blistering. In general terms it is recommended that prime coats should not be used when the salt contents exceed 0.5% TSS. If they are used then the surface dressing should be applied very quickly but this may be impractical in construction contracts. A scheme is presented in Fig 9 where the type of prime coat, salinity of surface to which it applied and recommended maximum permissible delays are related.
Plate 5. Site 2 (pan area) March 1994: note the barren tree-less terrain. The strip of surfacing enclosed by arrows was underlain by polyethylene sheet and was not salt-damaged.

Plate 7. Site 1 (non-pan area) March 1994: looking west: note presence of trees and bushes indicating less saline terrain. Carriageway with some damage caused by tracked vehicles (but not by salt). Indications of salt attack to the margins of the carriageway, shown by arrow.

7.2 SURFACE DRESSINGS

The surface dressings are much more resistant to salt damage than the prime coats. At Site 1, in the three years since traffic has been withdrawn, the double surface dressings have covered roadbases containing up to 1.1% TSS (in Sections 6 and 7) without showing salt damage. The single surface dressings have, however, been slightly damaged, particularly noticeable at the junction with the double surface dressing (see Plate 7). The probable reason for this is related to their reduced bitumen thickness compared to the double surface dressings. (The bitumen application rates were approximately 2.7 and 1.5 l/m2.)

The double surface dressings of Site 2 (saline subgrade) remained undamaged for as long as they were trafficked (six months) but they became progressively damaged after traffic was withdrawn (Plate 6). Even the least saline sections of Site 2, nos. 8 and 9, where salt levels in the top of the roadbase had reached about 1.2% TSS, became badly damaged. This salt level compares to 1.1% TSS in the upper 50mm of the roadbases of Sections 6 and 7, the most saline sections of Site 1, which were not damaged, as stated earlier. The double surface dressed access road to the Sua Pan salt factory, which carries quite heavy traffic, was undamaged two years after construction despite having been built adjacent to the airstrip on a saline subgrade. It is presumed that traffic opposes the upward force of the salt crystallization and maintains the adhesion between the bitumen and the roadbase. Thus, damage is prevented even when surface salt levels reach high levels, 1.5% TSS in the case of the road trial.

More salt deposition has occurred in the less saline roadbase sections of Site 2 (nos. 8,9,10 & 11) than the more saline sections (nos 12 & 13). It is probable that the amount of salt accumulation in the roadbases depends on the salt level of the saline sand fill, which remained at about 1.1% TSS throughout the duration of the trial.

From the standpoint of road construction, the preventative action of traffic must be regarded as a bonus and not as a design criterion; in situations where saline subgrades occur, additional preventative measures must be adopted. In this respect, the impermeable polyethylene sheet has been a success in the field trial up to the time of the last monitoring visit four years after construction.
Fig. 8 Botswana: salt damage field trial: changes in salt levels in roadbases under carriageway (0-50mm) after sealing
Prime type

CUTBACK (MC30)

Subgrade type

Saline

Non saline

Salt content at surface before priming % TSS

<0.20

>0.20

<0.42

>0.42

Permissible duration to seal

30 days

2 days

Seal immediately

No limit

2 days

Seal immediately

Prime type

EMULSION (Cationic)

Subgrade type

Saline

Non saline

Salt content at surface before priming % TSS

<0.31

>0.31

<0.66

>0.66

Permissible duration to seal

30 days

5 days

Seal immediately

No limit

10 days

Seal immediately

Notes:
1. For saline lower pavement or subgrade layers the recommended maximum time delay between base compaction and sealing is 30 days. This is the estimated time required for salts from a saline subbase or subgrade to migrate through a 150mm thick base.
2. A longer time delay to sealing would be possible if the base remains dry (ie moisture content below 6%).
3. A factor of safety of 2 has been applied.
4. Surface salts contents refer to 0–50mm depth from the surface.

Fig. 9 Relationship between prime type, delay to priming and salt content of bases
Black polyethylene sheeting, 0.25mm thick was used for the sections of the new road crossing the salt pan, altogether totalling 6km and costing approximately £0.3 per sq m. It was laid across the whole road width within a 50 to 100 mm thick layer of sand beneath the sub-base, and compacted with the sub-base. On average it was 350 to 400mm below the road surface. Three years later construction the condition of the road where the polyethylene had been laid was good, with no sign of salt in the roadbase. However, in caution, it should be understood that the coefficient of friction is low at this interface and could result in shear failure if traffic stresses exceed a safe value.

Considering the vulnerability of the bituminous prime coats to saline conditions, it would be useful to carry out further tests where surface dressings were applied directly to the roadbase and the prime coat excluded. In this field trial an initial problem was experienced with the lack of adhesion of the surface dressing to the roadbase but it improved with the passage of traffic. This effect has been observed elsewhere (Januszke et al, 1992).

8. CONCLUSIONS

1. Warm arid and semi-arid climates promote the accumulation of soluble salts in the upper layers of the road pavement. These can crystallise out beneath thin bituminous surfacings such as prime coats and surface dressings and damage them.

2. Prime coats are very vulnerable. If the soluble salt content, measured as percent Total Soluble Salt (TSS), exceeds approximately 0.3 % in the upper 50mm of the roadbase, they can be damaged. Cutback prime is more vulnerable than emulsion prime.

3. Surface dressings are more resistant than prime coats to salt damage. This trial, lasting four years, indicated that single and double surface dressings would not be damaged by roadbase TSS contents up to 1.0 %, provided the roadbases were constructed on a non-saline subgrade. If these salt levels are expected, a prime coat should preferably be excluded but a trial would be advisable to determine the effectiveness of bonding the surface dressing directly on to the roadbase. Alternatively, the prime coat could be surface dressed within three days of application but this may be impractical in contract situations.

4. Trafficking increases the resistance of surface dressings to salt damage; the thresholds in conclusion 3 were exceeded by 50% in the trial without damage. Surface dressed road shoulders are therefore vulnerable to salt attack.

5. Where surface dressings are applied to roadbases constructed on saline subgrades, it is recommended that an impermeable fabric should be placed beneath the roadbase to prevent the upward rise of salt and protect the bituminous surfacing from eventual salt damage. This measure was adopted with success in the field trial and in an actual contract situation without yet compromising road performance in other ways. The type, thickness and method of emplacement of the fabric should be carefully selected: in this trial polyethylene was successful but a thick bitumen layer was not.

9. ACKNOWLEDGEMENTS

This research was carried out by the Overseas Centre (Programme Director: Dr J Roll) of the Transport Research Laboratory in collaboration with the School of Civil Engineering, Birmingham University and the Ministry of Works, Transport and Communications, Botswana. It was funded by the Overseas Development Administration and the Ministry. The views expressed in this Paper are not necessarily those of the UK Overseas Development Administration or the Department of Transport.

The Botswana Ministry of Works, Transport and Communications funded the construction of the trials and provided technical assistance during the construction and subsequent monitoring. The authors are indebted to the Director, Deputy Director and many of the staff of the Materials Laboratory whose cooperation has contributed to the success of the project.

10. REFERENCES


Netterberg F and Maton L J (1975) Soluble Salt and pH determinations on highway materials. *Sixth regional Conference for Africa on Soil Mechanics and Foundation Engineering Durban, South Africa*


**APPENDIX A: DETERMINATION OF ELECTRICAL CONDUCTIVITY**

1. The sample is dried and sieved, retaining the passing 20mm fraction.

2. The retained sample is crushed and ground until all passes the BS 2.0mm sieve.

3. The ground sample is mixed with deionised water to achieve a 2:1 water-soil mix and left for 15 minutes with intermittent stirring. Sufficient sample is prepared to carry out duplicate conductivity measurements.

4. The mixture is poured into an electrolytic conductivity cell and the reading taken. Convert the conductance reading to absolute conductivity units by means of the following formula:

   \[ C = S \times k \]

   where \( C \) = conductivity (e.g., milliSiemens per cm)

   and \( S \) = Siemens

   and \( k \) = the cell constant (cm)

Most conductivity cells have a built-in compensator for automatically adjusting the readings against a reference temperature of 25°C.

All electrical conductivity measurements are quoted in milliSiemens per centimetre (mS/cm) at 25°C. A Siemen is the reciprocal of the electrical resistance measured in ohms.
### Botswana: Field trial, Site 1 (non-saline subgrade): results matrix

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<th>Section</th>
<th>1</th>
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<th>4</th>
<th>5</th>
<th>6</th>
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**Notes:**

1. Electrical conductivity, measured in milliSiemens/cm
2. N: No
   C: Cutback
   E: Emulsion
3. (0) No damage
   1) < 10% surface salt damaged
   2) 10-25% surface salt damaged
   3) 26-50% surface salt damaged
   4) 51-75% surface salt damaged
   5) > 75% surface salt damaged
### Botswana: Field trial, Site 2 (saline subgrade): results matrix

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**Notes:**
1. Electrical conductivity, measured in milliSiemens/cm.
2. N: No
   C: Cutback
   E: Emulsion
3. 0: No Damage
   1) < 10% surface salt damaged
   2) 10-25% surface salt damaged
   3) 26-50% surface salt damaged
   4) 51-75% surface salt damaged
   5) >75% surface salt damaged
4. A sheet of polyethylene, 0.55mm thick, was laid on the embankment below the calcrete base.
5. Bitumen emulsion prime (2.4l/m$^2$) was applied to the embankment below the calcrete base.
### APPENDIX C

#### Field trial: Salinity trends post priming, pre-surfacing: Site 1

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Note: Salinity expressed as conductivity, mS/cm

#### Field trial: Salinity trends post priming, pre-surfacing: Site 2

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