Prevention of Salt Damage to Thin Bituminous Surfacings: Design Guidelines

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A design method to prevent soluble salt damage to thin bituminous road and runway surfacings based on laboratory tests and field trials is proposed. Remedial treatments for damaged surfacings are also suggested. The damage, characteristic of warm islands and arid and semiarid inland regions of the world, occurs when salts crystallize in the pavement, physically disrupting the bituminous surfacing and causing premature deterioration of the road. Bituminous primes have been found to be more susceptible to damage than final surface dressings. The design method has been developed from laboratory studies in the United Kingdom and field trials in the West Indies and Botswana. They apply wherever a waterbound or a chemically stabilized pavement layer is covered with a thin bituminous surfacing.

Soluble salts in pavement layers, groundwater , or both can migrate upward to the surface and damage the thin bituminous surfacing. This migration through capillary action is mainly caused by evaporation at the surface. At or near the surface, the salts in solution become supersaturated and crystallize. This creates pressures with associated volume changes that can lift and physically degrade the bituminous surfacing and break the adhesion with the underlying pavement layer. The damage may appear in the form of "blistering," "doming," "heaving," "fluffing," and "powdering" of the bituminous layer.

Soluble salt is defined (*1*) as "basically those minerals that are most soluble, notably salts of magnesium and sodium." Gypsum (calcium sulfate), an abundant salt, is only slightly soluble and does not cause damage. This type of damage has been reported in southern and western Australia, southern and northern Africa, West Indies, India, Chile, United States, and the Middle East. By superimposing the location of recorded cases of surfacing damage from soluble salts onto Meig's (*2*) classification map of world climates, it is apparent that salt damage of bituminous surfacings is restricted mainly to warm islands and arid and semiarid inland regions where evaporation exceeds precipitation. Moisture is drawn to the surface where any soluble salts present can be precipitated.

The published work on soluble salt damage to bituminous pavements was reviewed by Obika et al. (*3*). The published papers deal with local climates and materials, and the recommendations cannot necessarily be universally applied. Whereas very small amounts of soluble salt (0.2 percent) can cause damage, higher percentages have been used without subsequent damage.

There appears to be a requirement to standardize methods of salt content analysis so that maximum salt limits can be compared. The sulfate values of Weinert and Clauss (*4*) are based on the analysis of water extracts, whereas Fookes and French (*5*) refer to acid-soluble sulfates. Netterberg et al. (*6*) quote sulfates as SO_4 and others [e.g., Weinert and Clauss (*4*) and Netterberg (*7*)] as SO_3. To relate SO_3 to SO_4, multiply the SO_3 value by 1.2. Cole and Lewis (*8*) used NaCl, and Weinert and Clauss (*4*) measured chloride.

The recommended salt limits refer to the initial salt content of the materials used in the pavement structure. However, tests have shown that, depending on temperature and relative humidity, the final salt content at the pavement surface before surfacing can be significantly higher than the initial amount. Ideally, it is desirable to specify the maximum salt content at the surface before bituminous surfacings. Practically, this value may have to be estimated as discussed later.

The design criteria developed in this paper are based on a review of previous work, laboratory simulations in environmental cabinets at the University of Birmingham in the United Kingdom, salt damage investigation and pilot trials in the West Indies associated with airfield pavement damage, and full-scale trials for a new road in Botswana constructed through known saline natural ground.

The laboratory work initiated to examine problems with bituminous surfacing in the West Indies (*9*) indicated that bituminous prime coats were particularly sensitive to damage from small amounts of salts contained in the pavement materials or groundwater, whereas bituminous surface dressings were more resistant to salt damage. The lack of traffic was considered to be a problem that is particularly important for airfield runways and sealed road shoulders.

Field trials in the West Indies and Botswana were constructed to confirm these findings and also to investigate the benefit of several preventive treatments. The details and results of these trials have been reported by Obika and Freer-Hewish (*10*) and Woodbridge et al. (*11*).

Objectives

A design method is proposed to prevent soluble salt damage to thin bituminous road and runway surfacings in warm islands and arid and semiarid inland regions. It is based on laboratory simulation testing of field conditions and field trials.

Factors Influencing Salt Damage

The factors influencing salt damage are climate, geology and hydrogeology, materials characteristics, pavement surfacing design, and construction practice.

Climate

Temperature, relative humidity, wind speed, and rainfall all influence salt damage. They affect evaporation significantly and hence the potential for upward salt migration. Temperature and relative humidity also determine whether salt crystallization thresholds are crossed. These aspects are discussed by Obika et al. (*12*). Precipitation influences the net water balance at a given location and also whether there is a seasonal or perennial moisture deficiency that could provide the conditions for a net upward saline moisture migration. Where rainfall is insufficient to leach out minerals from weathering rocks, in situ accumulation of mineral salts generally occurs.

Geology and Hydrogeology

The depth and quality of groundwater contribute significantly toward creating bituminous surfacing damage from salts. Saline groundwater may result from the solution of minerals present in sediments or from the ingress of seawater to the host material. The predominant type of salt depends on a variety of geochemical processes, the source of the salt, and the local climate. The most commonly encountered salt in many arid and semiarid zones is sodium chloride, known as halite.

In arid and semiarid zones, the capillary moisture rise can be more than 10 m (*13*). The height of the rise depends on a variety of factors, including porosity and temperature gradients.

Materials Characteristics

The various salt types that can contribute to the damage of pavements in dry lands include but are not limited to sodium chloride (NaCl), sodium sulfate (Na_2SO_4), sodium carbonate (Na_2CO_3), and magnesium sulfate ($MgSO_4$).

Fine-grained porous materials can encourage deleterious filamentous crystal growth, and the pore characteristics of the individual particles can influence the movement of saline moisture in the pavement layers. Obika et al. (*12*) discussed the nature and magnitude of salt crystal pressures. For materials of equal mechanical strength, those that contain large pores separated from each other by micropores are the most liable to salt weathering.

Pavement Surfacing Design

The type of bituminous surfacing and its application rate influence the rate of evaporation from the pavement surface and therefore the rate of upward salt migration. Pavement damage from soluble salts appears to be confined to thin bituminous surfaces, generally less than 50 mm thick. However, a few exceptions have been recorded in Algeria (*14*) and Australia (*15*).

In southern Africa, Netterberg et al. (*6*) discovered that damage from sulfates in mine waste pavement material could be prevented by applying a bituminous surface seal that had a ratio of permeability to thickness not exceeding 30 (permeability in millimeters per second, sufacing thickness in millimeters). Thick surfacings minimize evaporation and hence reduce migration and crystallization of salts at the surface.

Obika and Freer-Hewish (*9*) and Woodbridge et al. (*11*) showed that bitumen emulsion primes perform slightly better than bitumen cutback primes in reducing salt damage. The emulsion "sits" on the surface rather than penetrating into the base, thereby forming a less permeable surface than cutback primes. However, emulsion generally gives a poorer bond to the underlying pavement layer.

Construction Practice

The intervals between the construction of the pavement layers—a waterbound or cemented material, a bituminous prime coat, and a final surfacing, such as a surface dressing—can be critical if evaporation is high and if salts are present in the pavement material, the shallow groundwater, or both. Substantial salt accumulation may occur at the exposed surface in periods longer than 24 hr.

Brackish water is often used for compaction or curing of pavement layers. This method can lead to a significant precipitation of salt on the surface of the compacted layer. Also, there is evidence from laboratory studies and field observations to suggest a high risk of surfacing damage when salts in a pavement layer are subjected to repeated wetting and drying (solution and recrystallization).

RISK EVALUATION FOR BITUMINOUS SURFACINGS IN SALINE ENVIRONMENTS

Salt damage risk evaluation is recommended whenever a thin bituminous surfacing is proposed for a pavement in a warm island or arid or semiarid inland region. Clearly, the damage process is dependent on a complex interaction of many variables, but the proposed design method is based on two significant parameters, salt content and climate, which can be measured relatively easily. Further design parameters can be added as other variables can be linked to the damage process in qualitative terms. The procedure (Figure 1) first allocates values to salt levels in the pavement and subgrade materials, compaction, and, in some situations, groundwater and then allocates values to climatic conditions. The values are combined to provide an overall rating that indicates the damage risk for bituminous surfacings.

Salinity Levels of Materials and Water

Salinity values are required for pavement and subgrade materials, imported and in situ, and compaction and groundwater. Methods for determining salt content are given by Obika and Freer-Hewish (*10*), and it is im-

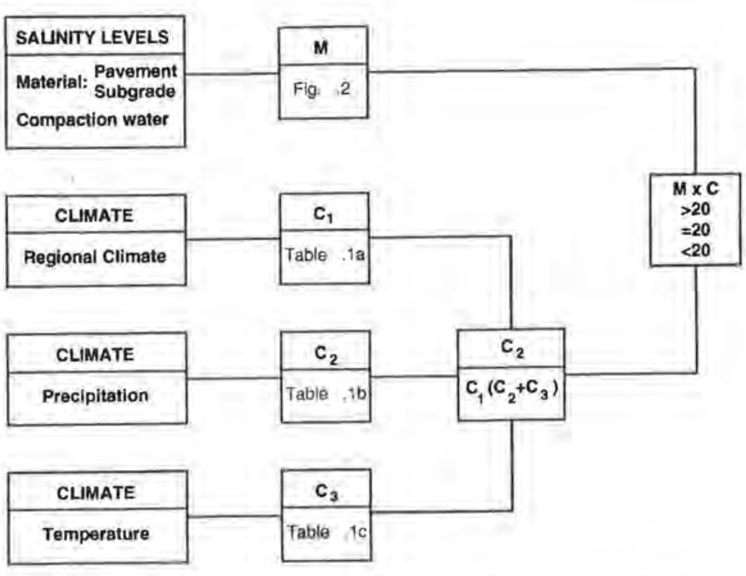

FIGURE 1 Risk analysis for salt damage to bituminous surfacings.

portant to adhere to these methods for consistency and comparability of results.

Salt Measurement

In the first instance, total soluble salts (TSS) will normally be measured; however, it is important to ascertain the dominant salt type for more detailed design and construction control, particularly if salt levels are significant.

Most of the analytical techniques available to determine salt content are time-consuming, and some require a considerable degree of skill. For this reason, methods have been developed whereby the electrical conductivity (EC) of an aqueous solution of the material is measured using a standardized procedure and the values are related to the percentage of TSS of the sample. The absolute relation of EC to 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, for example, by Doornkamp et al. (*16*) in the Middle East. The EC is measured in millisiemens per centimeter (a siemen is the reciprocal of the electrical resistance in ohms) at 25°C, and the TSS content is measured in mass percentage.

The correlation between the rapid EC and the TSS measurements for the Botswana field trials, where the TSS was measured according to the method given in BS 1377: Part 3 (*17*), was $TSS = 0.04 + 0.16EC$. A correlation coefficient of 0.9 was obtained for this relationship. All determinations were carried out on the minus 20-mm fraction of the samples, corresponding to about 75 percent by mass of the borrow pit material; it is generally recognized that the major proportion of the salt is contained in the fines.

Materials and Water Rating

Using the appropriate salt levels for materials and water, the weighting value M is determined from Figure 2. An M value of 10 should be adopted if the pavement or subgrade salinity exceeds 0.8 percent TSS regardless of compaction water salinity.

The salt content value used should be the maximum value obtained from the pavement or subgrade materials and may be measured in terms of either TSS or EC if calibrated locally for the materials used. Ideally, the salt content at the surface before bituminous surfacing should be used.

Climatic Conditions

Characteristics of the regional climate, seasonal precipitation pattern, and seasonal temperature pattern are required.

Climate Rating

The project site can be classified regionally as extremely arid to others in Table 1. A value (C_1) appropriate to the regional climate is assigned. Similarly, Tables 1b and c are used to assign values (C_2 and C_3) appropriate to the seasonal precipitation and temperature variations. The overall rating for the climate (C) is obtained by multiplying the sum of C_2 and C_3 by C_1.

Combined Risk Evaluation ($M \times C$)

The combined risk value is obtained by multiplying M by C. For MC values greater than 20, special design and construction measures may be required in order to prevent damage to bituminous surfacings. High MC values relate directly to high risk of salt damage. If the MC value is marginal, it is recommended that a detailed inquiry of the history and performance of existing thin surfacings be implemented. A visual inspection of existing surfacings, particularly for lifting and loss of adhesion between the bituminous surfacing and the underlying layer, is also desirable.

Design Procedures for MC > 20

Types of Bituminous Surfacing

For reasons discussed earlier, only surfacings less than 50 mm thick appear to have been damaged by salts, and the degree and rate of damage vary according to the type of bituminous surfacing.

Selection of Bituminous Primes and Primer Seals

The prime surfacings are the most susceptible to damage from salt crystallization, primarily because they are the thinnest and the least effective in reducing evaporation from the underlying pavement. Damage can occur within 2 days of application.

Type and Application Rate

Primes made from penetration-grade bitumen cutback with a highly volatile fluid such as kerosene are more susceptible to salt damage than primes made from an emulsion. Although emulsion is useful to alleviate the onset of salt damage, it can create a tacky surface that cannot be trafficked before final surfacing unless dusted with fine aggregate. Increasing the prime application rate and providing a thicker barrier to reduce evapo-

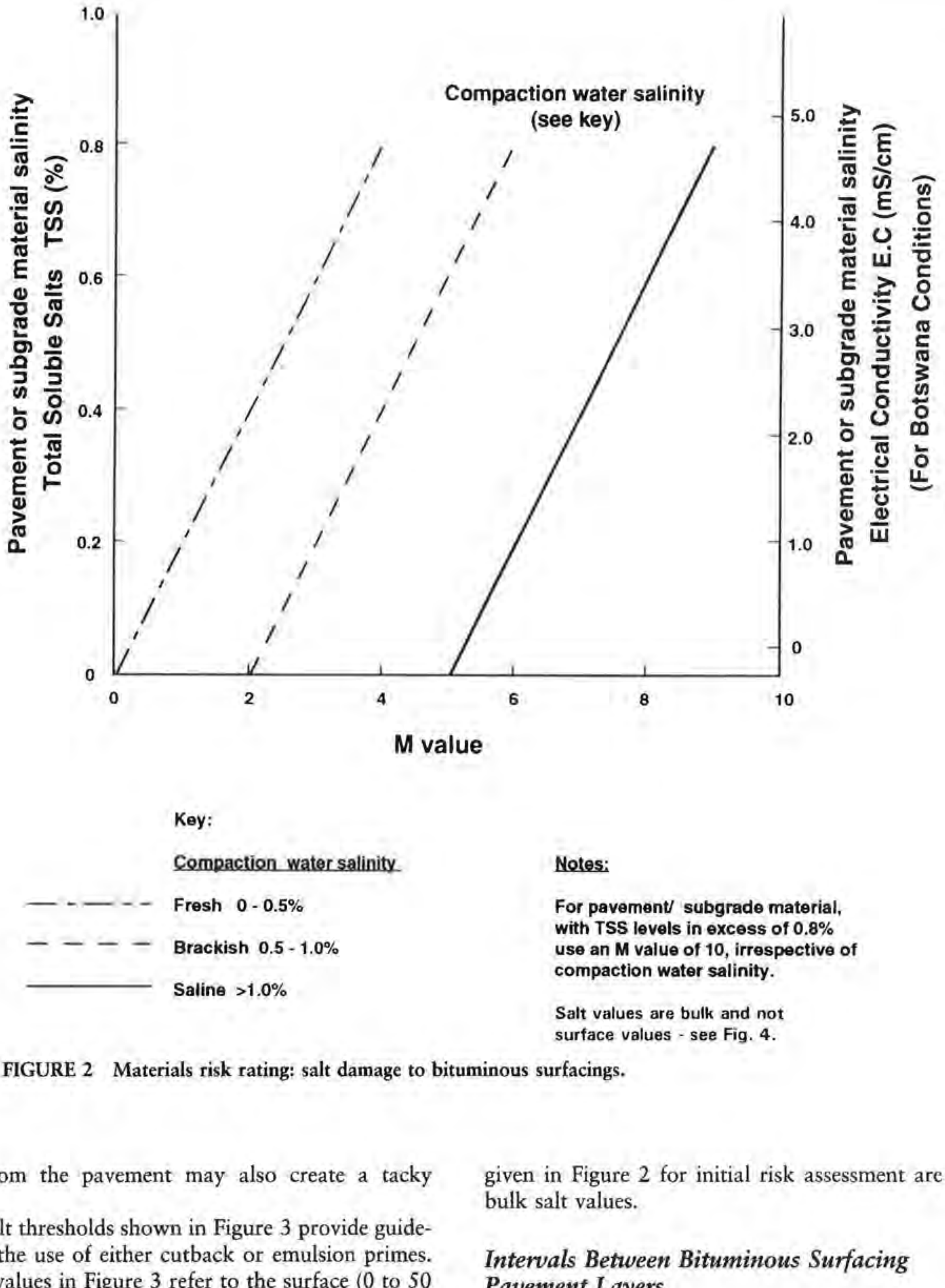

FIGURE 2 Materials risk rating: salt damage to bituminous surfacings.

ration from the pavement may also create a tacky surface.

The salt thresholds shown in Figure 3 provide guidelines for the use of either cutback or emulsion primes. The salt values in Figure 3 refer to the surface (0 to 50 mm) of the pavement just before sealing, and Figure 4 provides a relationship, obtained from the Botswana field trials, between initial salt content within the pavement material at construction and salt content at certain time intervals after construction. Ideally, trials on site to check this relationship are recommended. The values given in Figure 2 for initial risk assessment are initial bulk salt values.

Intervals Between Bituminous Surfacing Pavement Layers

From the foregoing discussion, it is clear that the time intervals between compaction of the road base and the prime and the surface dressing are important. Ideally, primes should be covered immediately if salts are present in the pavement.

TABLE 1 Salt Damage: Risk Evaluation for Climate

a)	Regional Climate:		C_1 Value
	Extremely arid		4
	Arid		4
	Semi-arid		6
	Island coastal		5
	Others		0
b)	Precipitation		C_2 Value
	No marked season of precipitation		2
	Summer precipitation		3
	Winter precipitation		1
c)	Temperature	Range	C_3 Value
	Zone T1	>30°C	3
	Zone T2	20-30°C	2
	Zone T3	10-20°C	1

When the pavement materials have a negligible salt content and there is the possibility of ingress of salt from the water table or subgrade, or both, through capillary action, vulnerable primes and primer seals should be covered within a week by a more substantial surfacing. Actual rates of moisture rise from the Botswana field trials appeared to be of the order of 5 mm/day (*10*). Figure 3 incorporates the time constraints for various conditions. Control of salt movement is another option and is considered below.

Selection of Permanent Surfacings

There is no evidence to indicate salt damage to thick surfacings (> 50 mm), and it is reasonable to assume that no precautions are required for these surfaces. Damage to thin permanent bituminous surfacings takes considerably longer to develop than damage to primes. This period can vary from one week to several years and may depend on the condition of the prime when covered by the permanent surfacing, the type and position of harmful salts in or below the pavement, and trafficking of the surface.

The importance of the impermeability of the bituminous surfacing as a means of retarding the upward rise of salt was mentioned earlier. Surface dressings appear to be impermeable; however, upward movement of moisture has occurred on some of the Botswana field trial sections. Moisture rise beneath impervious pavements has been noted before by Tomlinson (*18*) and Horta (*14*). Cracking of a surface caused by shrinkage, oxidation, or traffic would encourage localized evaporation and salt crystallization.

The salt content thresholds and time intervals between surfacing operations are shown in Figure 3. These values have been designed for protection of primes and are too conservative for the performance of single and double surface dressing seals, but, at present, precise salt-level thresholds for long-term performance of final surfacings have not been substantiated. The maximum salt content thresholds recommended for Botswana are shown in Table 2; the trials are still being monitored for longer-term performance.

The Botswana trials and other damage sites, however, highlight the importance of identifying whether the surfacing will be trafficked or untrafficked. Sealed shoulders and large portions of runway pavement areas are examples of the latter.

These trials indicate that stricter limits are required for untrafficked surfaces. The kneading action of traffic on surfacings appears to be very important in preventing damage and increases the resistance of surface dressings to salt damage. The road trials in Botswana showed detachment of single sealed shoulders alongside the intact double-seal trafficked carriageway.

Control of Salt Movement

When salts are inherent in the subgrade or groundwater, an impermeable plastic fabric can be introduced at the subgrade-pavement interface. This method was found to be effective in preventing the rise of saline water to the pavement surface and thus preventing surface damage, even though adjacent sections were damaged. A thick bitumen layer placed in the same position was not successful in preventing damage. In Botswana thin bituminous surfacings constructed on saline subgrades without an impermeable plastic fabric were damaged by salts.

Repair of Damaged Surfacing

Prime Surfaces

Damage detected in its early stages can be arrested by rolling, which may control further blistering until more layers can be added and adhesion with the underlying base can be regained.

For severe damage, rolling will not be successful and the surface must be broomed to remove the prime. When the underlying base is still sound, a new spray technique following the guidelines above can be used, but if the base consists of soft aggregates, brooming can

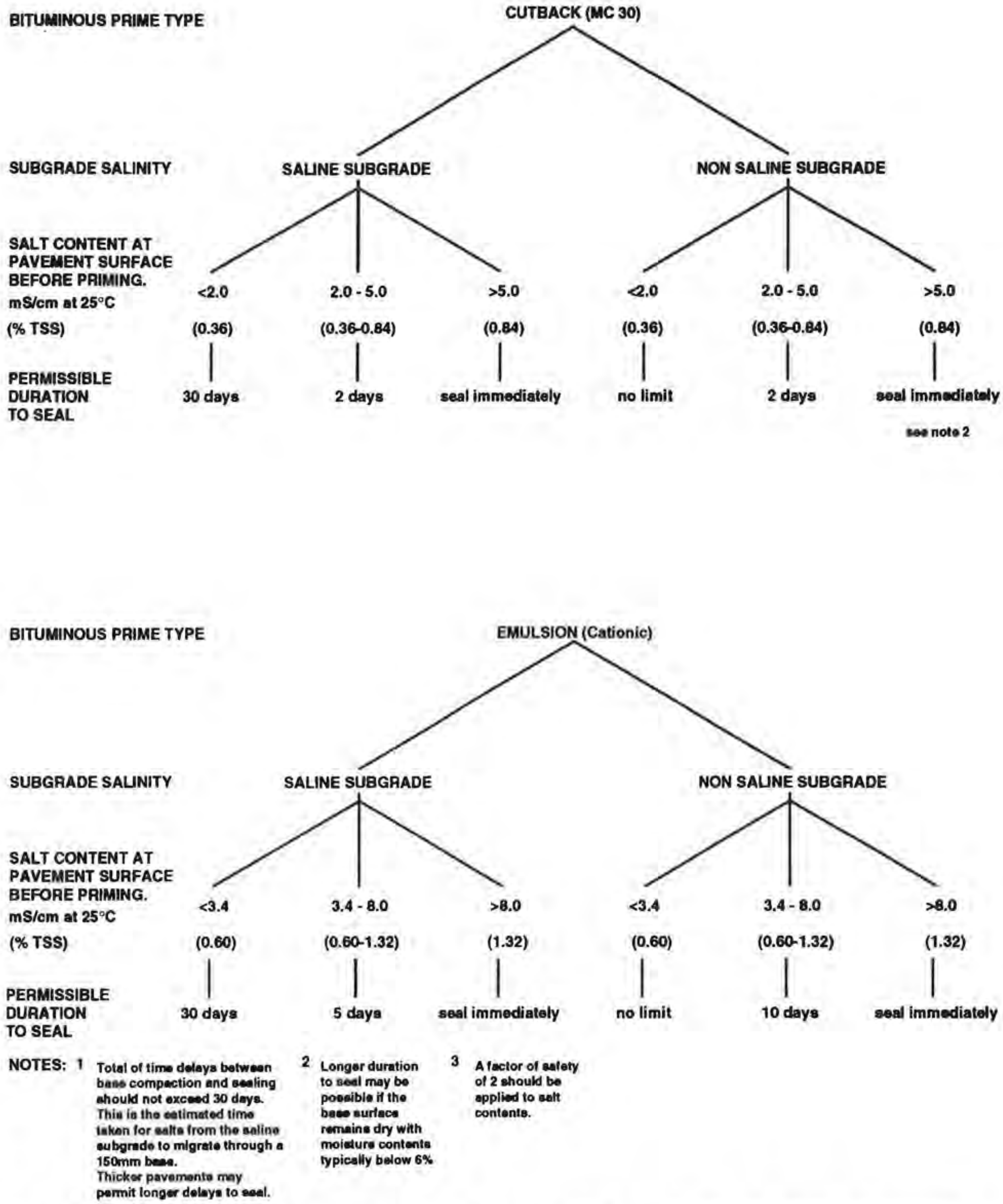

FIGURE 3 Permissible intervals between prime and final surfacing in relation to subgrade salinity and pavement surface salinity.

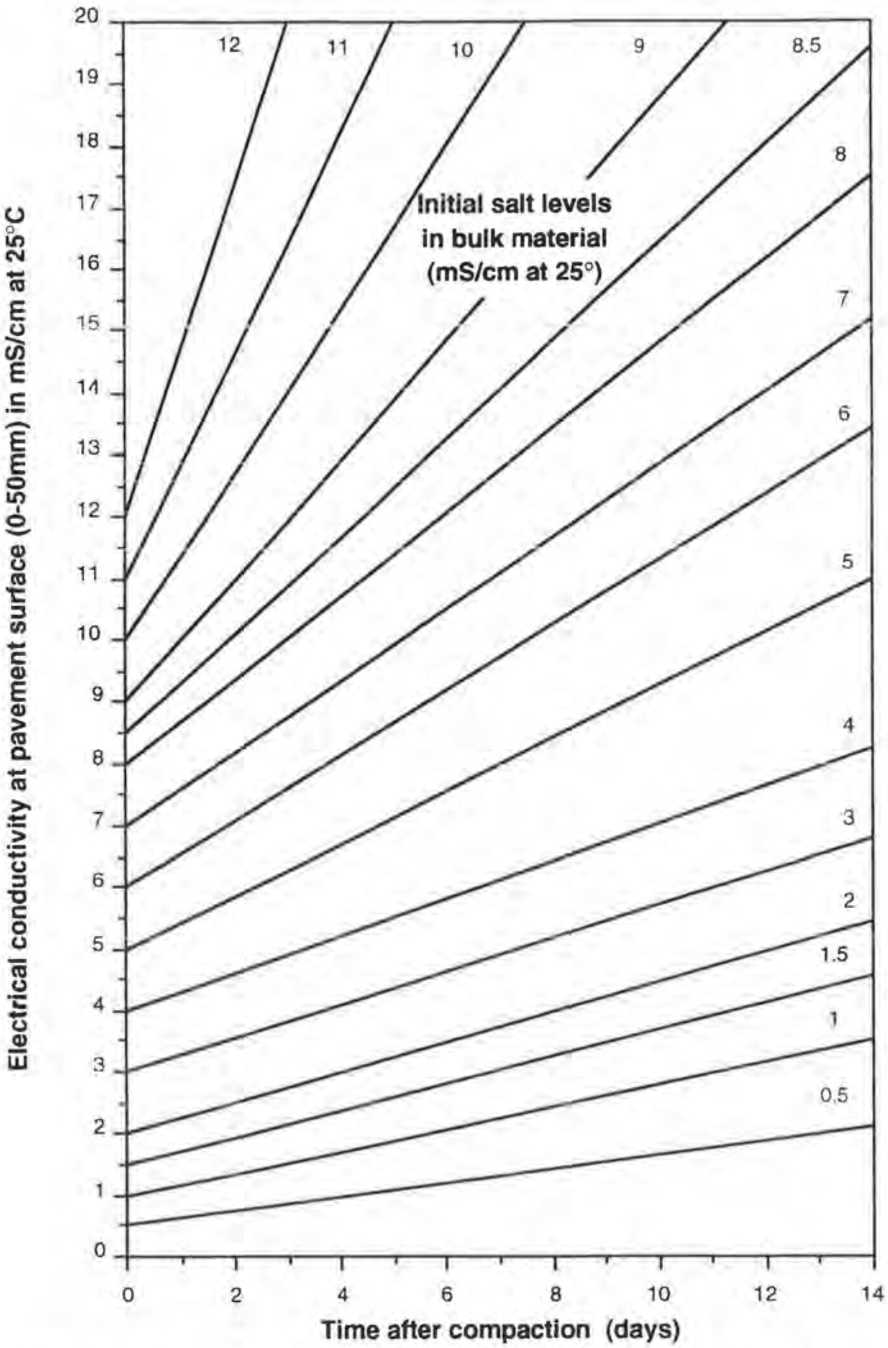

FIGURE 4 Electrical conductivity readings at surface of a layer with time for initial conductivity levels of bulk material for Botswana trial site.

damage the base surface. It may then be difficult to regain the same surface level and quality without scarifying to at least 100 mm.

Final Bituminous Surfacings

Small failures should be treated locally by removing the surface and hand spraying a new surfacing, possibly replacing cutback bitumens with emulsions and increasing the application rate without risking severe bleeding.

CONCLUSIONS

In warm arid and semiarid climates, where evaporation exceeds precipitation, soluble salts accumulate in the

TABLE 2 Suggested Minimum Salt Limits for Botswana Project

Surface Type	Traffic Status	Subgrade Condition	Maximum total soluble salt content at surface prior to priming % TSS (0-50 mm sample depth)	
			Emulsion Prime	Cutback Prime
Prime			0.30*	0.20*
Single Surface	Untrafficked	Saline	0.30	0.15
		Non Saline	-	-
"	Trafficked	Saline	0.90	0.70
	"	Non Saline	>1.20	>0.80
Double Surface Treatment	Trafficked		>2.0	>1.0

Notes:

1. *A factor of safety of 2 has been applied.*
2. *For the Botswana calcrete TSS % = 0.04 + 0.16 x Electrical Conductivity (E.C.).*
3. *Salts can be inherent in pavement materials or introduced with brackish/saline compaction water.*
4. *If initial salt contents only are known, obtain an estimate of surface salt content for the appropriate time delay using Fig. 4.*

* *Increased if construction process speeded up to satisfy Fig. 3.*

upper layers of the road pavement and can damage thin bituminous surfacings such as prime coats and surface dressings. The results of laboratory and field studies have identified the importance of climatic factors such as humidity and temperature, intervals between the construction of each pavement layer, surfacing types, and trafficking. The design procedure shows that single values of salt limits, as suggested in other reports, are not appropriate for all surfacing types and construction procedures.

A procedure for risk evaluation of potential salt damage has been developed based on the laboratory and field trials. Risk ratings are assessed for materials, compaction water and groundwater, and climatic conditions for different surfacing types.

Bituminous prime coats are very sensitive to salt damage and can be damaged if the soluble salt content exceeds 0.3 percent TSS in the roadbase material as a whole. Cutback prime is more sensitive to damage than emulsion prime.

Surface dressings are more resistant than bitumen primes to salt damage because of their increased bitumen thickness. The Botswana trial indicated that trafficked single and double surface dressings would not be damaged by roadbase TSS contents up to 0.5 and 1.0 percent, respectively. Trafficking appears to increase the resistance of surface dressing to salt damage. Surface-dressed road shoulders and large areas of runway are especially vulnerable to salt attack at lower salt content levels.

For salt levels at the upper acceptable limits, a prime coat should preferably be excluded, and trials would be advisable to determine the effectiveness of bonding the surface dressing directly onto the roadbase. Alternately, the prime coat could be surface dressed within 2 days of application, but this may be impractical in contract situations.

When traffic is withdrawn from hitherto sound sections, the surfacing becomes damaged.

Methods of preventing the upward rise of salts in solution were incorporated into the trials in Botswana, and an impermeable fabric (plastic) placed at the bottom of the roadbase prevented the upward rise of salt and protected the bituminous surfacing from salt damage without compromising road performance. A thick bitumen layer placed in the same position was not successful in this respect. The technique of a cutoff membrane has been applied to the new road in Botswana.

Remedial treatments for salt damage consist of rolling at early signs of damage followed by further surfacing immediately or removal of damaged material and replacement to the requirements of the design method described in this paper.

ACKNOWLEDGMENTS

The research was carried out by the School of Civil Engineering, University of Birmingham, in collaboration with the Overseas Centre of the U.K. Transport Research Laboratory for the Overseas Development Administration and the Ministry of Works, Transportation and Communications, Botswana. The latter two organizations funded the work. Ove Arup and Partners, Botswana, and Wallace Evans and Partners, U.K., also supported the work described in the paper.

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