

5. PREVENTATIVE DESIGN PROCEDURES FOR MC > 20

5.1 Types of Bituminous Surfacing

For reasons discussed earlier, only surfacings less than 50 mm thick are normally damaged by salts, and the degree and rate of damage varies according to the type of bituminous surfacing.

5.2 Selection of Bituminous Primes

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

Prime 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. Whilst the use of emulsion is useful to alleviate the onset of salt damage, it can create a ‘tacky’ surface, which cannot be trafficked prior to final surfacing, unless dusted with fine aggregate. Increasing the prime application rate and hence providing a thicker barrier to reduce evaporation from the pavement may also create a “tacky” surface. The salt threshold values shown in Figure 5.1 provide guidelines for the use of either cutback or emulsion primes.

For long term performance of final surfacings, the maximum salt content thresholds recommended for Botswana are shown in Table 5.1, which refer to the surface (0-50 mm) of the pavement just before sealing. Figure 5.1. Provides a relationship, obtained from Botswana field trials, between initial salt content within the pavement material at the time of construction and salt content at certain time intervals after construction. Ideally, trials on site to check this relationship are recommended. The salt content thresholds and time intervals between surfacing operations, as given in figure 5.1, have been designed for protection of primes. Note that the values presented in Figure 5.2. (used for initial risk assessment) are initial bulk salt values.

Construction - Time Intervals between bituminous surfacing and construction of pavement layers

From the above, 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.

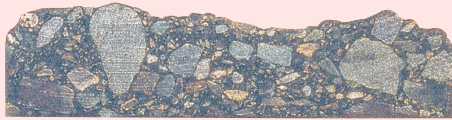
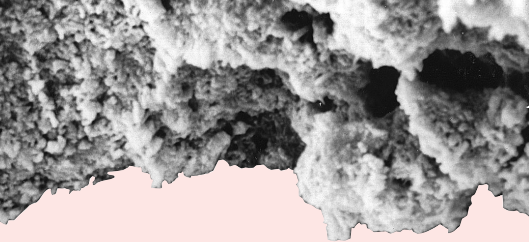
In the situation when the pavement materials have a negligible salt content and there is the possibility of ingress of salt from the water table and/or subgrade through capillary action, then vulnerable primes and primer seals should be covered within a week by a more substantial surfacing. Figure 5.1 incorporates the time constraints for various conditions. Control of salt movement is another option and is considered below.



Cattle will congregate and leak salt from the road shoulders if salts are present in materials. This causes a traffic hazard as well as erosion of the road shoulder.

Caution Salt values at Surface (0-50mm) are required for ascertaining appropriate preventative measures whereas bulk salt content (i.e from sample of whole material) is used for the initial risk assessment.

Actual rates of saline moisture rise in pavement from the Botswana field trials appeared to be of the order of 5-mm/day.



Double Otta Seals (between 30 - 40 mm in thickness) are relatively impermeable. In areas where there is a potential for salt damage, Otta seals should be considered as an alternative to other seals

5.3 Selection of Permanent Surfacing

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 roads in Botswana field with double surface dressing. Cracking of a surface caused by shrinkage, oxidation and/or traffic encourages localised evaporation and salt crystallisation.

Stricter limits are required for untrafficked surfaces. The kneading action of traffic on surfacings is very important in preventing damage, and increases the resistance of surface dressings to salt damage. Cases of salt damage in Botswana show detachment of single sealed shoulders alongside intact double seal trafficked carriageway.

5.4 Control of Salt Movement

When the salts are inherent in the subgrade and/or groundwater an impermeable plastic fabric can be introduced at the subgrade/pavement interface. This has been found to be effective in preventing saline water rising to the pavement surface, thus preventing surface damage. A thick bitumen layer placed in the same position is usually not successful in preventing damage.



Shoulder deterioration can also be caused by other factors such as insufficient binder spray rate.

Bituminous surfacings constructed on saline subgrades without an impermeable plastic fabric have a high probability that salt damage will occur to the surfacing.

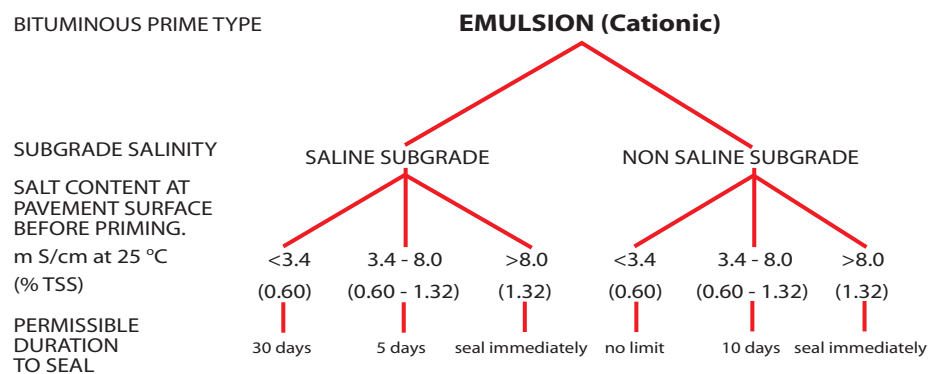
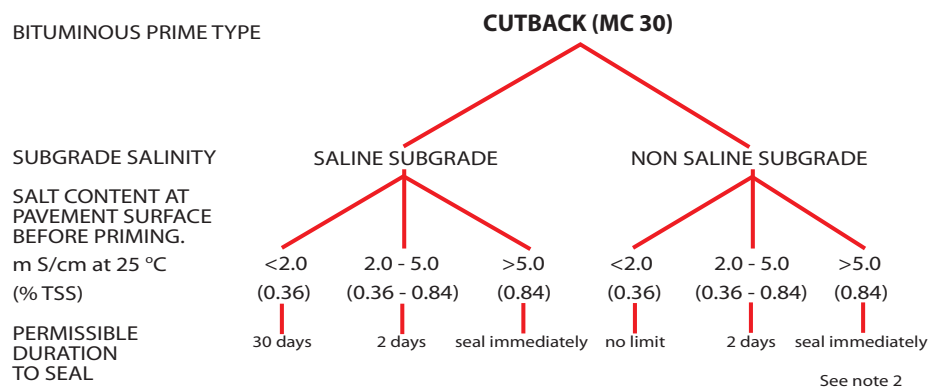


Figure 5.1 Permissible intervals between prime and surfacing in relation to subgrade salinity and pavement surface salinity.

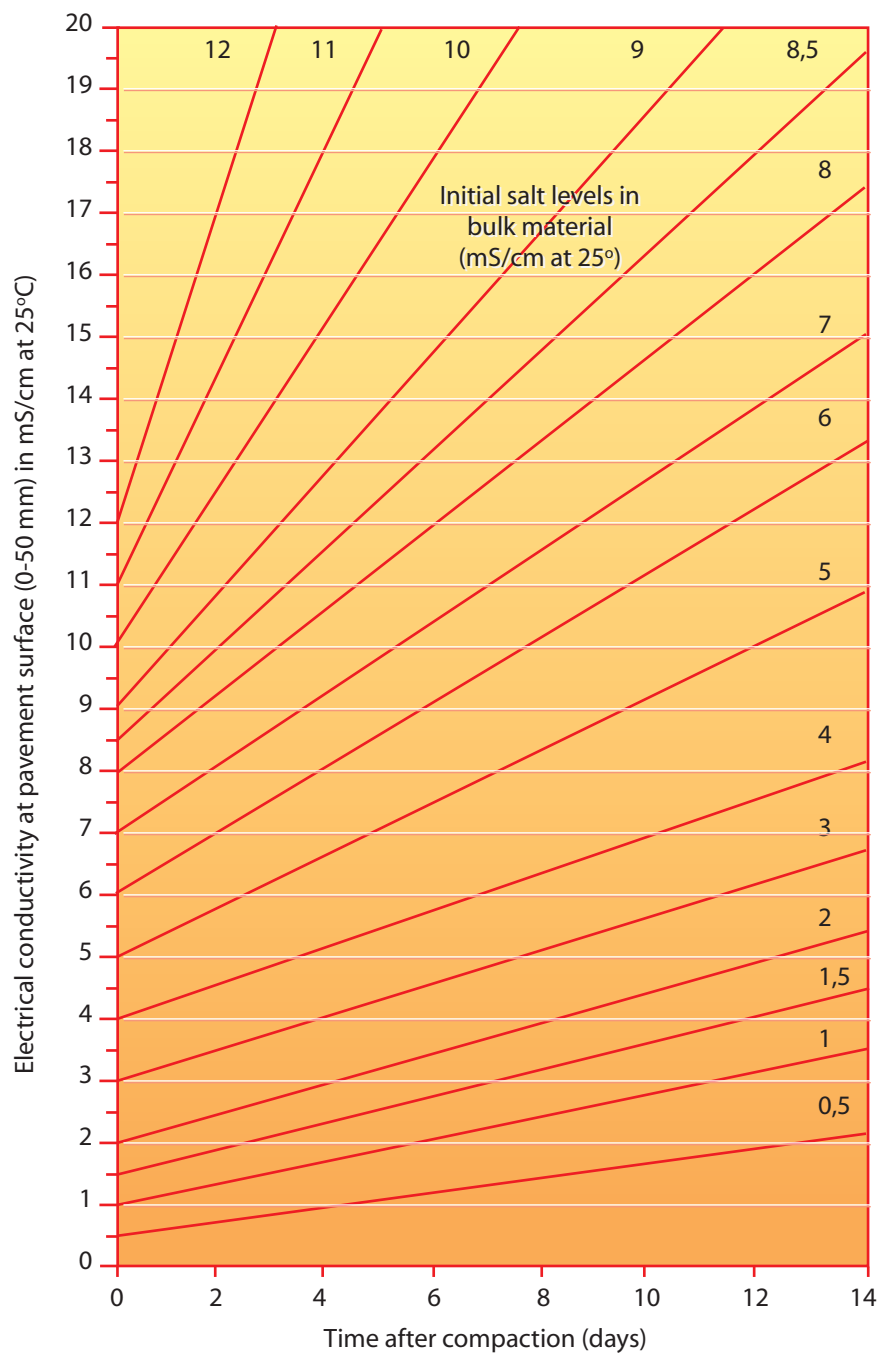
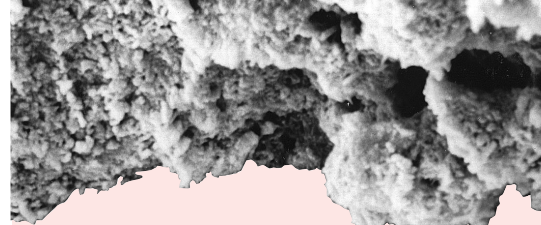


Figure 5.2 Electrical conductivity readings at the surface (0-50 mm) of a layer with time for various levels of initial conductivity of the bulk material.

Table 5.1 Suggested maximum salt content limits for Botswana.

Surface Type	Traffic Status	Subgrade Condition	Maximum total soluble salt content at surface prior to priming (E.C mS/cm) (0-50 mm sample depth)	
			Emulsion Prime	Cutback Prime
Prime	-	-	1.60	1.0
Single Surface treatment	Untrafficked (Shoulders & airstrips)	Saline	1.60	0.70
		Non Saline	-	-
Single Surface	Trafficked (>50 vpd)	Saline	5.40	4.10
		Non Saline	>7.25	>4.75
Double Surface treatment	Trafficked (>50 vpd)	Saline	>12.25	>6.0
		Non Saline	-	-
Single Otta with sand cover seal	Trafficked (>50 vpd)	Saline	>12.25	>6.0
		Non Saline	-	-
Double Otta Surfacing	Trafficked (>50 vpd)	Saline	>15	>8
		Saline	-	-

Notes:

1. A factor of safety of 2 has been applied. Values refer to salt content at surface (0-50 mm) prior to priming. If initial salt contents are only known, obtain an estimate of surface salt content for the appropriate time delay using Fig. 5.2.
2. For Botswana Total Dissolved Salt, $TDS \% = 0.04 + 0.16 \times \text{Electrical Conductivity (E.C.)}$.
3. Salts can be inherent in pavement materials or introduced with brackish/saline compaction water. The values refer to total salt content at surface (0-50 mm) irrespective of source.
4. Values for Otta seal have been estimated from known relative impermeability of Otta seals.

6. REPAIR OF DAMAGED SURFACING

6.1 General

There are not many methods available for cost effective repair of damaged surfacings. The repair technique adopted will depend on the severity of damage and project specific considerations. Those which have been used successfully in Botswana and elsewhere are described below.

6.2 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 may be regained with the underlying base.

For severe damage, rolling will not be successful and the surface has to be broomed to remove the prime. In situations when the underlying base is still sound a bitumen rubber reseal can be used, but if the base consists of soft aggregates brooming can damage the base surface. It may then be difficult to regain the same surface level and smoothness without scarifying to at least 100 mm.

6.3 Final Bituminous Surfacing

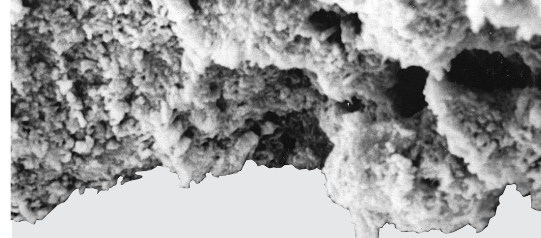
Small failures should be treated locally by removing the surface and hand spraying a new surfacing, possibly replacing cutback bitumens with emulsions and increasing the application rate without causing the risk of severe bleeding.

6.4 Resealing with Bitumen Rubber

Where economically feasible, damaged surfacings should be replaced with bitumen rubber seal. The top 50 mm of the existing base course should be removed and replaced with either asphaltic material or gravel before resealing with bitumen rubber double surface treatment. This remedial measure is not applicable when salts are present in the subgrade, providing a source of continuous replenishment of salt. Under the latter situation a cut -membrane should be inserted at the top of subbase or subgrade prior to sealing with a conventional binder or bitumen rubber.

6.5 Damage caused by Sulphate Salts

In the infrequent cases where damage is caused by acidic sulphate salts it is possible to neutralise the salts by mixing lime into the saline pavement material. This forms insoluble salts which do not cause damage.



A base course layer with high salt content. The prime has been exposed too long before the surfacing is applied and deterioration of the prime is the result.

Acidic sulphate salts caused damage to Phikwe runway.

7. SUMMARY

In the semi-arid climate of Botswana evaporation exceeds precipitation, soluble salts accumulate in the upper layers of the road pavement and can damage bituminous surfacings such as prime coats and surface dressings.

Studies have identified the importance of climatic factors and intervals between the construction of each pavement layer, surfacing types and trafficking. The design procedure show 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 in Botswana. Risk ratings are assessed for materials, compaction and ground water, 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% TDS in the road base material as a whole. Cutback prime is more sensitive to damage than emulsion prime.

Surface dressings and Otta seals are more resistant than bitumen primes to salt damage due to their increased bitumen thickness. In Botswana trafficked single and double surface dressings will generally not be damaged by road-base TDS contents up to 0.5% and 1.0% respectively. Trafficking appears to increase the resistance of surface dressing to salt damage. Surface sealed 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 where other engineering considerations, such as adhesion to road-base, allows. Alternatively, the prime coat could be surface dressed within two days of application but this is sometimes impractical in contract situations.

Interestingly, on withdrawal of traffic from hitherto sound sections, the surfacing became damaged.

When the subgrade is saline and pavement layers comprise non saline materials, impermeable fabric (plastic) placed at the bottom of the roadbase prevents upward rise of salt and protects the bituminous surfacing from salt damage. If placed with care, drainage and long term performance is not compromised. A thick bitumen layer placed in the same position has not been successful in this respect. The technique of a cut-off membrane has been applied to roads in Botswana.



Single salt blister, exposing the base layer.



Salt dome, which will break under traffic and



- resulting in an exposed base.

8. REFERENCES

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APPENDICES

Appendix A - Maximum Salt Content Limits worldwide

Appendix B - Field Electrical Conductivity measurement of soils by the quick conductivity method

Appendix C - Risk Evaluation and Determination of required preventative measures - worked example

Appendix D - Glossary of Terms

Appendix E - Abbreviations

APPENDIX A: MAXIMUM SALT CONTENT LIMITS WORLDWIDE

Author	Salt	Maximum Limit	Material Location	Criteria/Remarks
Cole & Lewis (1960)	Chloride as NaCl	0.2% (0.5% may be safe)	Sandy clay soils and lateritic gravel base semi-arid - Western Australia	Observations of soluble salt damaged base courses and laboratory tests with compacted gravels to which various amounts of salt solution had been added. No damage was encountered with materials containing up to 0.5% but authors suggest 0.2% and warn against the limited scope of their tests. Method of salt analysis not given. Soluble salt damage in Western Australia results mainly from capillary rise of chloride in groundwater.
Weinert & Clauss (1967)	Chloride Sulphate as SO_3 - (mostly MgSO_4)	0.2% 0.05%	For road foundations materials generally but principally for quartzite mine waste South Africa	Chloride limit adopted from Cole & Lewis (1960). Sulphate limit suggested from considerations of the critical limit (ie 0.05%) for building stones and sulphate content of base materials where damage had occurred. Salt contents as obtained by analysis of 5:1 water: soil extracts. Analysis was carried out on material obtained from the top few inches of base probably after upward migration of salt took place. Damage in this case, resulted from the use of saline construction material.
Netterberg (1970)	As an indication of total sulphate	Reject material if electrical conductivity is >1.5 mmhos/cm at 15.8°C . If 0.6-1.5 mmhos/cm test for sulphates and reject if $>0.05\%$. If 0.06% mmhos/cm accept material	For any base and sub-base material. South Africa.	Conductivity limits correspond to salt limits suggested by Cole & Lewis (1960) and Weinert & Clauss (1967). Electrical conductivity can be used as a rapid indication of salinity, however it has a major drawback in that it does not identify the type of salt present. Applicable only to quartzite mine waste construction material as conductivity/salinity relationship varies depending on the material.
Netterberg, Blight, Theron & Marais (1974)	Total soluble salt Total soluble sulphate	0.2% 0.15%	Base and sub-base materials. Witwatersand quartzite mine waste - see Weinert & Clauss. South Africa	Authors stress the peculiar nature of the experience (mine waste material) upon which the suggested limits are based. Sulphate analysis carried out on water extract. Note: some authors (eg Fookes & French 1977), Netterberg 1979) refer to acid soluble sulphate. The salts considered are from quartzite mine waste construction materials.
Blight, Stewart & Theron (1974)	Total soluble salt (mostly sulphate)	2% (3% may be safe)	For sand used for asphaltic mixes. South Africa	Observations of asphaltic surfaces of various ages made with sulphate bearing sands. Also laboratory tests on specimens containing various quantities of added soluble salt.

Author	Salt	Maximum Limit	Material Location	Criteria/Remarks
SABS 1083 - 1976 (South African Bureau of Standards)	Total soluble salt	0.5%	South Africa	Quoted in Netterberg (1979). Based on an understanding that total soluble salts when determined will include other harmless salts in the material. Therefore 0.2% of Netterberg et al (1974) considered too stringent. Soluble salt content determined on water extracts.
Blight (1976)	Total soluble salt	0.2%	Base and sub-base materials	The salts discussed are sulphates of predominantly magnesium and iron. Author suggests that 0.2% can also be applied where the salt is predominantly chlorides. The limit does not acknowledge that sulphates are more deleterious than chlorides.
Fookes & French (1977)	-	Varies with traffic and other stipulated conditions		Primarily on field experience in the Middle East and on assessment of the type of materials and conditions found in that region. Authors point to the possible effect of salt mixtures on the limits specified and take into account the predominant type of salts in the region.
Netterberg (1979)	Sulphate as SO ₃ according to BS1377	0.3%	Lime and cement treated materials if cohesive	Criteria for suggested limits not discussed. Determinations are carried out on water extracts. Materials similar to that discussed in Netterberg et al (1974).
	According to BS1377	0.5%	If not cohesive	
	Total soluble salt	2.0%	Untreated material - fines	
Sir William Halcrow & Partners (date unknown)	Acid soluble sulphate	0.3%	Wearing course and base course material	Experience of road construction in the Middle East.
	Acid soluble sulphate	0.5%	Roadbase and hard shoulder	
	Acid soluble sulphate	2.0%	Sub-base	

APPENDIX B

FIELD ELECTRICAL CONDUCTIVITY MEASUREMENT OF SOILS BY THE QUICK CONDUCTIVITY METHOD

EQUIPMENT:

Electrical conductivity meter such as the Portec PI 8140
Porcelain conductivity cup or similar
Spatula, 1 x 5 litre bottle of distilled water
Wash bottle, 1 x 50 ml graduated beaker and glass stirring rod
Box of tissues

SAMPLING:

Using the spatula, scoop the fine grained (<2 mm) portion of soil to be tested (approximately 5 to 10 g) into the beaker. (More than one scoop may be required to make up to approximately 10 g).

PROCEDURE:

1. Connect the conductivity cup to the metre and calibrate to zero using the distilled water or in accordance with the manufacturer's instructions.
2. Into the graduated beaker containing the soil sample add distilled water up to 20 ml mark.
3. Using the glass stirring rod, stir the soil-water mixture for approximately 2 minutes.
4. Whilst still stirring, pour the mixture into the conductivity metre.
5. Adjust the scales and read the electrical conductivity in Siemens per metre, at 25° C.

Note:

Most field conductivity metres assume that the mixture is at 25° C (the reference temperature). Therefore if the temperature of the mixture is significantly different, a temperature compensation will be required (refer to TMH 1). In practice, most field conductivity measurements will not require temperature compensation as the results are only intended to provide a rapid indication of salinity and potential for salt damage.

REPORTING:

The results of Field Electrical Conductivity Measurement should be reported in millisiemens per centimetre (mS/cm) or Siemens per metre (S/m) at a standard reference temperature of 25° C.

WATER SAMPLES:

The conductivity of Water Samples can be measured directly by pouring a sample of the water directly into the conductivity cup.

APPENDIX C

RISK EVALUATION AND DETERMINATION OF REQUIRED PREVENTATIVE MEASURES-WORKED EXAMPLE

INTRODUCTION

This example follows the Procedure described in Chapters 4 and 5 of the guideline. There are two steps. First step is to establish whether the condition for salt damage exists. This is done by looking at the climatic and salt content data to obtain a risk rating. Step 2 involves determining the prevention measures required. The following hypothetical case is used for illustration.

PROJECT DATA

Project location: Village of Kang, Western Botswana.

Road Construction: 150 mm subbase, 150 mm base. Assumed OMC: 10% moisture content.

Surfacing: carriageway: Double surface treatment (trafficked)

Shoulder: Single seal with sand cover seal (untrafficked).

Climatic Conditions

Regional climate: Semi-arid

Annual mean temperature: 26°C

Rainy season (precipitation): During Summer months

Typical daily temperature range: Winter..... 0 - 30°C - Range: 30

Summer..... 15 - 42°C - Range: 27

Salinity Conditions

Sub-grade: non saline

Calcrete Sub-base material: 0.4% TDS (or 2.25 E.C)

Base Course material: 0.4% TDS (or 2.25 E.C)

Compaction water: 5000 mg/l

A- OBTAINING THE RISK RATING

Stage 1: Obtaining M-Value

From Fig. 4.2

Read Pavement Materials Salinity on vertical axis (i.e. 0.4% TSS).

Move horizontal to Brackish water (middle diagonal line) since the compaction water is brackish.

Move downwards from this point to intercept M-Value.

This is the Materials Risk Rating M-Value (M = 4)

Stage 2: Obtaining Climatic Risk Rating

From Table 4.1

Since the Kang region is semiarid, select C_1 value of 6, $C_1 = 6$

a) Since the rain falls during the Summer months select C_2 value of 3 (i.e. Summer precipitation), $C_2 = 3$

b) Since the typical daily temperature variation is between 20° and 30° (i.e. 27 and 30 from our data for Kang), select C_3 value of 2, $C_3 = 2$

Stage 3 Obtaining the combined C value

Obtain combined climatic risk rating (C) by multiplying sum of C_2 and C_3 by C_1 , i.e. $C = (3+2) \times 6 = 30$

Stage 4: Obtain an overall risk value (MC) for Kang

By multiplying M-Value by combined C-Value, i.e. $MC\text{-Value} = M \times C = 4 \times 30 = 120$

As the MC-Value for this particular project in Kang is greater than 20, there is a potential for salt damage to occur. Therefore design of Preventative Measures are required. An example of this is given below:

B - DESIGN PREVENTATIVE MEASURES**Stage 1: Determine total salt content level in pavement materials as follows:**

1. Approximate quantity of salt to be added through construction water:
From the data, the OMC is 10% (add 3% for evaporation): $= \frac{13}{100} \times 0.5 = 0.065\% \text{ TSS}$
2. Salt content already present in materials = 0.4% TSS

Therefore total salt content in pavement materials = $0.065 + 0.4 = 0.465$ or 2.7 mS/cm

(Note conversion to E.C using the following formula: $\text{TSS} = 0.04 + 0.16 \text{ EC}$ (See section 4))

Stage 2: Estimate the likely increase in salt content at the pavement surface (0-50 mm) that will result from evaporation after compaction

From Fig. 5.2

- a) Select the number of days constructed base is likely to be exposed before priming (horizontal axis). (10 days is used for this example).
- b) Draw a vertical line to intercept the 2.7 mS/cm diagonal lines (i.e. the initial built materials salt content).
- c) Draw a horizontal line from this intercept and read off the likely salt content at the pavement surface on the vertical axis = 5.5 mS/cm.

Stage 3 Determine the allowable time delay between priming and final surfacing

From fig 5.1

The permanent surfacing must be placed to cover the prime immediately (within 24 hours) if Cutback Prime is used. If Emulsion prime is used, the permanent surfacing can be placed up to 10 days after priming.

Specifications:

For the example provided, a possible specification could be as follows:

- There is potential for salt damage to occur if the saline pavement materials and construction water are used.
- In order to avoid salt damage:
 - The constructed base should not be exposed for periods exceeding 10 days. (or if exposed for more than 10 days more stringent (shorter) time delays between priming and sealing must be adopted).
 - Bituminous Cutback Prime, if used, should be sealed with permanent surfacing within 24 hours.

It is recommended that Bituminous Emulsion Prime is used instead of Cutback Prime. The Emulsion Prime should not be exposed for more than 10 days before the permanent sealing is constructed.

APPENDIX D - GLOSSARY OF TERMS

Soluble Salts	Salts that have high solubility in water at normal temperature and pressure.
Solubility	The process of solid “dissolving” in a liquid solvent to form solutes.
Crystallise	Formation of solid crystals from a solution. Sometimes termed “precipitation”.
Saturation	The point achieved when the concentration of solutes (salts) in the solvent (water) are at equilibrium at the prevailing temperature and pressure conditions.
Supersaturation	The point reached when the concentration exceeds the equilibrium concentration resulting in crystallisation of the solute.
Crystal Pressures	The forces generated during crystallisation and the growth of crystals.
Capillary action	The process of moisture movement inside small interconnecting pores of soil brought about by attractive forces between the moisture and walls of the pores.
Electrical conductivity	The reciprocal of electrical resistance measured in ohms and provides a measure of the concentration of solutes (salts) in the solution.
Crystal habit	Refers to the shape and form of the crystal.
Halite	Sodium chloride solid crystals, major component of common salt used for cooking.
Whiskers	Crystals that have “hair like” shapes which tend to form at high supersaturation and have high disruptive crystal pressures.
Hygroscopic	Attracts moisture.
Hydration	The process of incorporation of moisture molecules in the crystal during crystallisation.
Salt damage	The process of physical degradation of road surfacings due to pressure exerted during crystallisation and crystal growth.
Chloride	Compounds with chlorine as the dominant anion, such as NaCl.
Total Soluble Salt (TSS)	The quantity or concentration of soluble salts in a given quantity of solvent (water).
Total Dissolved Salt	The quantity or concentration of soluble salts in a given quantity of solvent (water).
Maximum Salt Limits	The concentration of Total Dissolved Salts below which salt damage is unlikely to occur.

APPENDIX E - ABBREVIATIONS

BS	- British Standards
C Value	- Risk of Salt damage occurring in due to Climatic conditions
EC	- Electrical Conductivity
EPM	- Electron Probe Microanalysis
M C Value	- Risk of Salt damage occurring due to combination of materials and climatic factors
M Value	- Risk of Salt damage occurring due to Materials salinity.
MC	- Medium Curing
MgSO ₄	- Magnesium Sulphate
mS/cm	- milli siemens per centimetre
Na ₂ CO ₃	- Sodium carbonate
Na ₂ SO ₄	- Sodium Sulphate
NaCl	- Sodium Chloride
NORAD	- Norwegian Agency for Development Cooperation
NPRA	- Norwegian Public Roads Administration
OMC	- Optimum Moisture Content
pH	- Hydrogen ion concentration
PHN	- Public Highway Network
PPM	- Parts per million
S/M	- Siemens per metre
TDS	- Total Dissolved Salt
TMH 1	- Technical Methods for Highways
TSS	- Total Soluble Salt
UK	- United Kingdom

