Techniques to use on roads affected by salinity

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1 INTRODUCTION

There is no doubt that salinity and rising water tables affect the road infrastructure. The casual observer will see culverts and deteriorating roads, leading to conditions that are unacceptable, sometimes dangerous, and inextricably linked with rising salinity levels.

A simple description of the salinity issue in the context of roads is damage caused by salt and water with water or high levels of moisture being a common cause of pavement distress on local roads and highways. The condition of groundwater salinity is a complex issue of water and salt cycles above and below the ground. Much of the damage to road infrastructure in Australia appears to be due to rising water tables and high saline contents (McRobert, 1999 and O'Flaherty, 2003). The extent of the problem and areas at particular risk for road infrastructure were well documented in an Austroads report published in 2004 (Austroads, 2004a).

The effects of salinity on pavements may include (see Figure 1):

- rutting or pot holing in granular pavements
- differential shape loss resulting in rough pavements
- seal "blister" leading to loss of seal, water infiltration and potholing
- corrosion of steel reinforcement and subsequent spalling of concrete
- crumbling of concrete kerbs

Salt penetrating a bitumen seal	Extensive salt penetration in car park with bitumen seal	Damaged seal resulting in pot hole

Figure 1 Various forms of distress from salinity in urban roads (O'Flaherty, 2003).

It seems unlikely that salinity has any benefits to road infrastructure. Salt itself however, can be of use in pavements and has been successfully used to deice roads in cold climates and also to stabilise some materials for unsealed roads in remote areas of Australia.

This paper focuses on the impact of salinity on urban roads where it is assumed that a kerb and gutter is used at the edges of the road pavement. Both light and heavily trafficked routes are considered in this paper.

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This paper examines:

- new and existing roads,
- the impact of salinity on the road easement
- the impact of moisture in pavements
- the potential impact of roads from urban salinity
- possible design and construction techniques to minimise the impact of salinity
- whether there are special issues to consider in the recycling of cement in saline areas
- how lime stabilisation reacts with wet and salty conditions

2 New versus existing roads

Modern urban roads use the ‘umbrella’ approach to capture water from the surface by utilising appropriate levels and grades from the crown of the road. The aim of the ‘umbrella’ approach is to prevent water from entering the pavement layer and subgrade and to direct water into drain inlets with all run-off contained in pipes and discharged into a river, harbour or waterway.

A prime aim of road designers is to ensure that water does not penetrate through to the materials below the wearing course where it may weaken these materials. This can be achieved by using a sprayed seal, asphalt or concrete surface layer.

The common structure of roads is described in Figure 2 and these terms are used in the paper.

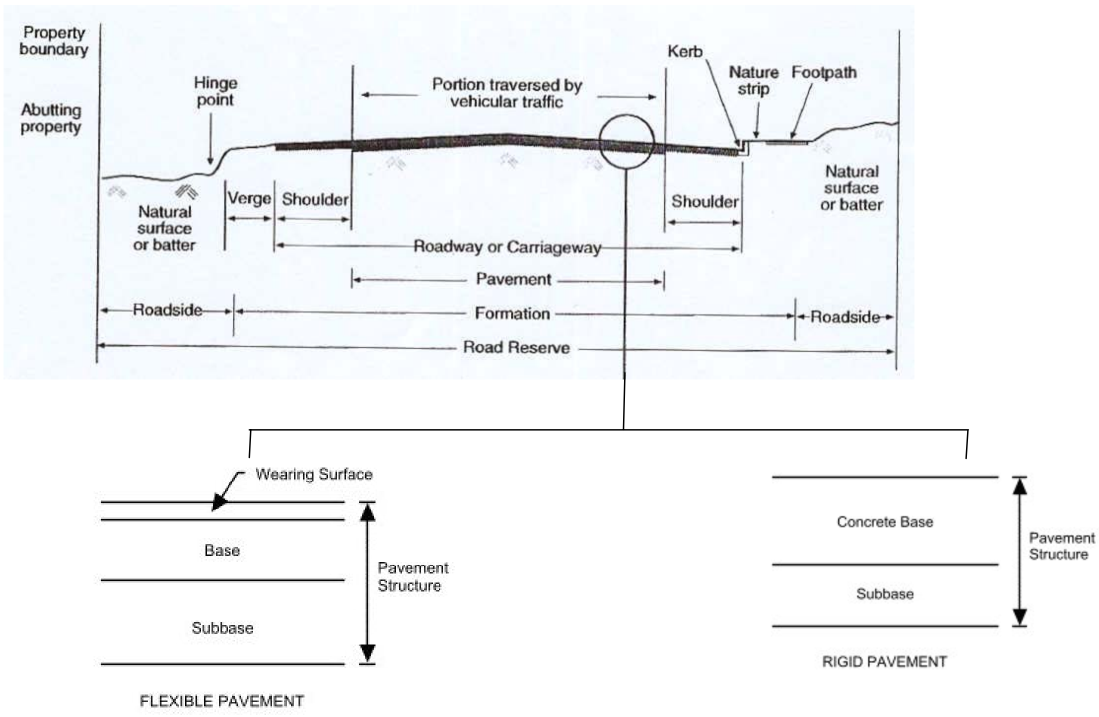
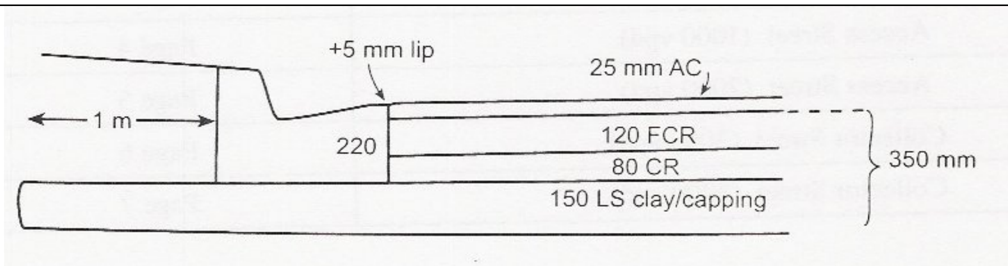


Figure 2 Road structures in the road easement (Dickinson, 1984).

Distress to the road infrastructure by urban salinity is due in part to moisture movements. Whether an engineer is designing a new road in a saline area or rehabilitating an existing road, limiting moisture movements below the surface is the key to minimising early distress to the roadway.

When the existing network shows common signs of distress in roads designed and built to common engineering standards, it would normally signal that these standards need to be upgraded. Wyndham City Council (west of Melbourne) reviewed their minimum road construction details in the 1990s when they were looking for long term solutions to overcome early distress in their urban and rural network where the roads were mainly supported on expansive subgrade materials (Foley, 2000). The outcome was to develop standard pavement configurations (see Figure 3) for local roads with different traffic levels suited to reducing moisture movements to the subgrade and which caused pavement shape loss.

It was also recognised that these configurations would cost the developer additional funds to construct roads but as Council would eventually maintain these roads, minimising the extent of early distress was more preferable than further rehabilitation costs at later stages of the development with rate payers having to cover these costs. Figure 3 shows some of the solutions developed by ARRB Transport Research - note the extent of stabilisation beyond the kerb and gutter.

<table>
<tr><td>Access Land & Access Place
Granular pavement with thin bituminous surfacing with lime stabilised clay subgrade</td><td>
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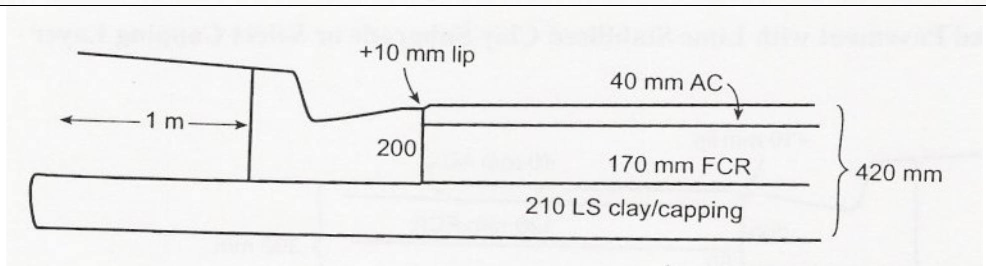
<tr><td>Access Street
(2000 vpd)
40mm of asphalt surfaced pavement with lime stabilised clay subgrade</td><td>
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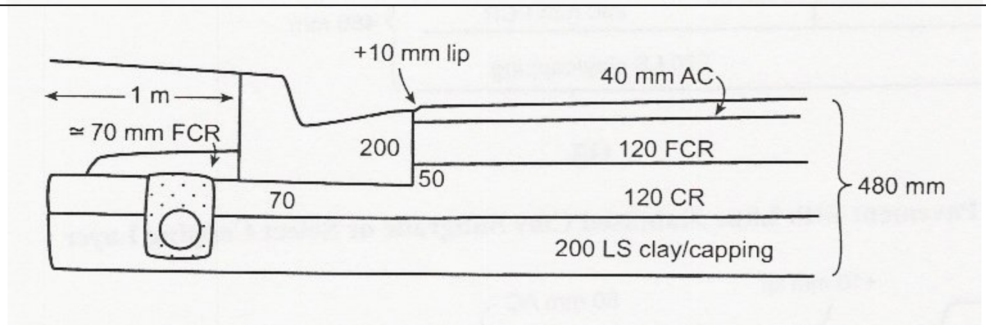
<tr><td>Collector Street
(6000 vpd)
Asphalt surface pavement with lime stabilised clay subgrade</td><td>
</td></tr>
<tr><td colspan="2">Notes: AC = asphalt, FCR = Fine crushed rock, CR = Crushed rock, LS = Lime stabilised</td></tr>
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Figure 3 Standard pavement configurations incorporating lime stabilised subgrades designed by ARRB Transport Research for Wyndham City Council (Foley, 2000).

A key issue in dealing with urban salinity is a consultation process between Councillors, developers and local government engineers to come to some agreed minimum standards that would be accepted by the community. In some cases, the best solution may be to avoid developments or the rezoning of regions with the municipality. Engineers then need to communicate to managers and Councillors why common road building standards are inadequate for salinity sites and that higher standards of design and construction will incur greater costs.

In highway pavements, the standards of construction are higher than those for local government roads due to the heavy traffic and because the closing of lanes to allow regular maintenance is discouraged in urban sites. The pavement configurations developed by many of the SRAs usually incorporate thick layers of asphalt or concrete, and kerb and gutters to drain water from the surface. Highways in urban environments drain to the median or spoon drains at the edges, and in some cases longitudinal drains are used to take water from the surface or median reducing the potential for water to enter the formation.

In Western Sydney, the M4 motorway passes dry land salinity areas and yet there is no direct signs of surface or pavement distress. This may be due to the depth of the pavement structure and the lack of additional watering on the median vegetation.

One approach to reducing the impact of salinity is to increase vegetation with long roots to lower the water table. Whilst it is recognised that large items of vegetation may become a safety hazard there is a possible happy medium as shown in Figure 4.

Figure 4 Vegetation used on the M5 Motorway, southwest of Sydney.

3 Moisture in pavements

Most practitioners attempt to remove excess subsurface moisture to improve the bearing capacity of the pavement to repetitive wheel loading. Adequate surface and subsoil drainage is essential for pavements to reach their desired pavement life[2]. The Austroads pavement design guide (Austroads, 2004b) notes the following factors that influence the moisture regime within and/or beneath a pavement and which must be assessed at the design stage (also see Figure 5):

- rainfall/evaporation pattern,
- reactivity of subgrade to variation in the moisture regime,
- permeability of wearing surface,
- depth of watertable or to water-bearing strata,
- relative permeability of pavement layers,
- whether or not to seal shoulders,
- type of vegetation to be used in medians or on verges, and their proximity to the pavement,
- the form of pavement construction (boxed or full width),
- pavement drainage, e.g. availability of table-drains, sub-surface drainage, etc.

[2] Obviously not the case in dry inland sites unless a high water table exists.

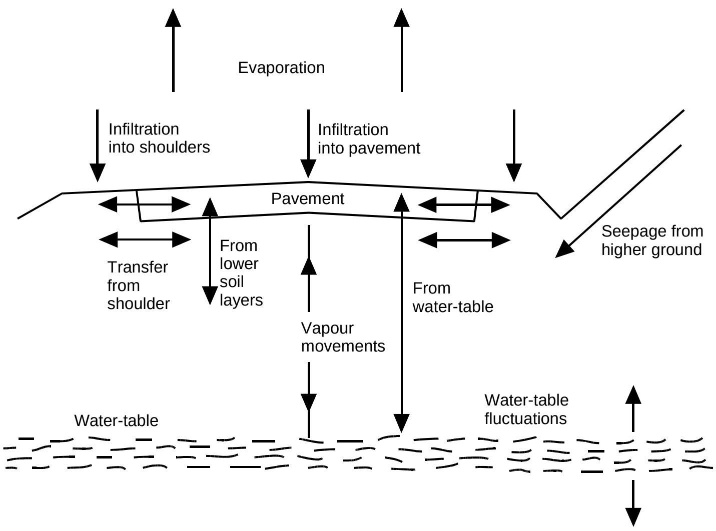

Figure 5 Moisture movements in road pavements (Austroads, 2004b)

The rate at which water enters a porous material such as granular materials used for roads, depends not only on the permeability, but also on the water pressure into the material and the capillary rise drawing the water into the material. The capillary rise of a soil or pavement material depends on the effective particle size of a soil and if it is unbound or bound.

It is accepted that capillary rise is inversely proportional to the coefficient of permeability and the relationship may be expressed as:

. $$h_c = \frac{a}{\sqrt{k}} \qquad \text{Equation 1}$$

where hc = capillary rise (mm)
k = coefficient of permeability (µm/s)
a = value depending on material

Work by Waters, indicated that 'a' is 5,000 for a single particle size and about 125 for granular materials (Waters, 1991).

The height of the sample used for a capillary rise test is 100 mm. Therefore, if the water reaches the top of the granular material sample, the permeability is 1.6 µm/s. However, in the field the capillary rise is much higher and sample height may need to be revised to accommodate field conditions or the timing of the capillary rise on short samples appropriately adjusted.

A requirement noted by VicRoads in their code of practice (VicRoads, 2004), is for a capping layer with a maximum permeability of 5×10^{-9} m/s (5×10^{-6} µm/s) which equates to a capillary rise of 45 m if 'a' is taken as 100. Therefore, if one is to soak a sample that meets the capping layer permeability requirement, the capillary rise is well above the sample specimen height. The challenge is to establish whether permeability or capillary rise is a better criterion for selecting a base material.

Capping layers
The capping layer shall be a Type A earthworks fill material with a permeability < 5 x 10-9 m/sec (5 x 10-7cm/sec) measured at Optimum Moisture Content (OMC) ± 5% and compacted to a Density Ratio of 98% ± 1% using Standard compactive effort. (VicRoads, 2004)

Table 1 Examples of the permeability rates for various soils (O'Flaherty, 2004)

Texture	**Structure** [D]	**Infiltration**	**Permeability (mm/h)** [A]
Sand	Apedal	Very Rapid	> 120[B]
Sandy Loam	Weekly pedal	Very rapid	> 120
.	Apedal	Rapid	60 - 120
Loam	Peds evident	Rapid	60 - 120
.	Weakly pedal	Mod. Rapid	20 - 60
.	Apedal	Mod. Rapid	20 - 60
Clay loam	Peds evident	Mod. Rapid	20 – 60
	Weakly pedal	Moderate	5 – 20
	Apedal	Slow	2.5 - 5
Light clay	Highly pedal	Moderate	5 – 20
.	Peds evident	Slow	2.5 - 5
.	Weakly pedal	Very slow	< 2.5
Medium to heavy clay	Highly pedal	Slow	2.5 – 20[C]
	Peds evident	Very slow	< 2.5
	Weakly pedal	Very slow	< 2.5
Clay	Sodic and saline	Moderate	8.0
.	Saline	Very slow	< 2.5
.	Highly saline	Extreme	< 1.0

NOTES: A. 1 mm/hr = 2.78 x 10^{-7} m/sec B. Can be measured > 250 mm/hr
C. Strongly structured polyhedral subsoils eg Krasnozem D. Ped is an individual, natural soil aggregate. Apedal means that in the moderately moist state, none of the soil material occurs in the form of peds; it is massive or single grain and when distributed separates into fragments or primary particles.

4 Impact of urban roads on salinity processes

Urban roads are unlikely to have any impact on further salinity if surface water is captured by drains and if drainage outlets are suitably located. The roads should be maintained such that surface water does not pond[3] and will not find its way through cracks leading to more water in the subgrade.

Austroads released a guide for the geometric design of major urban roads, but unfortunately did not recognise urban salinity as an issue (Austroads, 2002). Whilst the notes in the text box (see next page) are valid for normal drainage conditions, the second last bullet point regarding infiltration is unlikely to assist with urban salinity problems.

The pavement structure depth for local roads is about 400 to 500 mm and it has been noted that this may cause the water table to rise on the uphill side of the hill where the roadway traverses (see Figure 6). In urban situations, various techniques such as subsurface drains can be located orthogonal to the road centreline and below the stabilised subgrade layer to allow a flow of ground water across the road. Planting shrubs and trees that lower the height of the water table would be an advantage to keeping the water table away from the surface.

[3] Ponding of water should be avoided as it may cause hydroplaning of wheels.

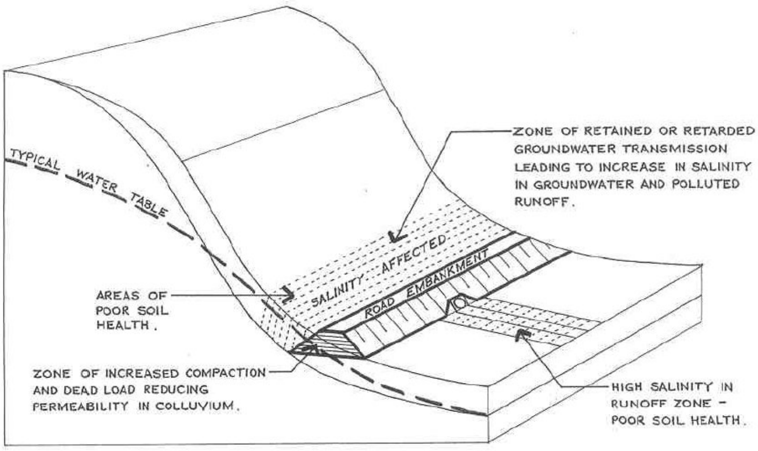

Figure 6 Roads and the pavement materials may cause an obstruction to moisture making its way down a hill (Porter, 2001).

In cuttings, care must be taken to establish the height of the water table and ensure sufficient subsurface drainage away from the cutting to avoid the pavement and easement being saturated. The amount of subsurface moisture is sometimes underestimated and insufficient grade is given to pipes leading to silting and lower flows.

In 2002 the IPWEA published a manual on salinity and identified the following (but are not limited to) issues to be addressed for risk management protocols for engineers working in salinity areas (IPWEA, 2002):

- effective underdrainage of all new roads and paths
- use of non-corrosive materials in subterranean and surface works
- insulation of pipeline materials
- installation of localised pump out systems to control elevated groundwater levels
- underdrainage, insulation and moisture protection of all footings and foundations
- implementation of effective tree replacement programs
- implementation of water conservation programs
- specification of salt tolerant plant species in specified areas
- installation of underdrainage to sporting fields & parks
- specifications for block and site drainage to avoid ponding
- development of garden management specifications and protocols including lists of appropriate deep rooted
- plant species
- specify drip irrigation systems for all new subdivisions
- retrofitting of interlot stormwater (roof) drainage
- removal of septic tanks and replacement with sewerage reticulation (where feasible)
- leakage identification and reduction
- land clearing regulations

Drainage – General
Any roads, including major urban roads, should have an adequate drainage system:

- Stormwater should be collected and conveyed from a catchment to its receiving waters with minimal nuisance, danger or damage, and at a developmental and environmental cost which is acceptable to the community as a whole.
- Drainage systems should be designed to operate safely with social, economic and environmental consequences that are acceptable to the community during 'major' and extreme rainfall events. Solutions adopted should ensure rapid restoration of the network following such events.
- Potential flood impacts associated with roadways, and their drainage systems, should be limited to acceptable levels for both public and private property, located either upstream, adjacent to or downstream of the road reserve.
- Implementation of the drainage system is to be consistent with 'Catchment Management Plans', 'Floodplain Management Strategies' and local and regional 'Stormwater Management Plans'.
- The impact of road development (increased imperviousness and channelisation) should be minimised by appropriate stormwater management measures. These may include controlling and temporarily retaining and/or infiltrating as much rainfall/runoff as possible.
- Drainage structures should be designed to provide access across road corridors for both terrestrial and aquatic fauna when a need is identified.

- land-use and surface runoff issues

The first on the list regarding effective underdrainage of all new roads and paths supports the approach in this paper that the management of drainage on and below the surface is vital to ensure optimum long term outcomes in managing urban salinity.

5 Design and construction techniques

5.1 General

Every element of the road structure has a specific role and figure x shows the commonly used terms to describe the road. This section looks at the impact salinity may have on various elements of the road, and offers some solutions.

Work by Vorobieff and others (Vorobieff, 2001) notes some possible methods to assist roads withstand the effects of salinity:

- raise the existing pavement level with suitable material and stabilise the top layer/s to strengthen the material to carry heavy traffic,
- stabilise the subgrade to reduce susceptibility to moisture changes,
- design subsurface drainage systems, and
- extensive planting of trees in the road reserve to bring down the water table.

All of these options are suitable for urban roads, although raising the road levels is expensive if manhole services have to be raised to accommodate the new levels.

The following sections consider the various elements, surfacings, pavement structure, and kerb and gutter in more detail.

5.2 Surfacings

In urban roads the following road surfaces are used (Austroads, 2003b):

- asphalt
- bituminous slurry
- concrete including insitu concrete, segmental pavers and flags
- sprayed treatments

Evidence to date indicates that salinity is only likely to affect sprayed seals and concrete surfaces that have not been designed taking high salt contents into consideration. Light seal treatments such as primes and primerseals, are likely to be distressed due to salinity and the Austroads spray sealing guide (Austroads, 2003b) notes that the most effective treatment is to apply a substantial seal treatment (see Table 2). The values for the salt content are based on the fines of the material and not the whole sample of material extracted from the roadway.

Table 2 Treatment of unsealed pavements containing salt (Januszke, 1984).

Salt content of fines (%)	Preliminary Treatment Method
0 - 1.5[A]	Apply a prime
1.6 - 2.5[B]	Apply a primerseal followed as quickly as possible by the final seal.
2.6 – 3.0	A sacrificial primed surface swept and followed by a primerseal and final seal may be satisfactory otherwise treat as for 3.0%+
> 3.0	Special investigations will be required, and techniques developed. No single method can be sure of success.
Notes: A: Salt content for material passing the 2.36 mm sieve, is determined gravimetrically by drying the saturation extract in a microwave oven. B: For salt content less than 2.5%, a primerseal with 10 aggregate and AMC4 primerbinder sprayed at 1.8 L/m^2 should be satisfactory (RTA, 2003).	

Aggregates and water used for sprayed sealing are normally specified with low quantities of chloride and sulphate ions[4].

Segmental pavers are known to be porous and as they move laterally over a period of time their porosity would increase. Whilst a well compacted and designed concrete mix is durable against salt, the 'umbrella' approach to managing pavement drainage is not useful in this instance. Further discussion on permeable paving is contained in the next section of the paper.

Concrete surfaces[5] are very durable against salt when both material and functional design are taken into consideration. When unplanned cracking occurs, it is recommended that the crack is repaired (typically using cross-stitching) and sealed to reduce water infiltration. With continuously reinforced concrete pavements, the regular fine cracks that develop allow water to enter the subbase and subgrade. As these fine cracks cannot be sealed, a designer should consider suitable subsurface drainage to minimise the water flowing into the subgrade (or formation) layer.

5.3 Pavement structure

5.3.1 General

Saline water will distress a pavement according to the function and type of the material within the pavement, and therefore, the following sections are considered:

- Unbound materials for base and subbase layers
- Modified and bound materials
- Insitu concrete
- Permeable concrete segmental paving
- Subgrade materials

[4] RTA specifications seek a maximum of 600 and 400 parts per million of chloride and sulphate ions respectively.
[5] As shown in Figure 1, a concrete base incorporates a wearing surface.

5.3.2 Unbound materials for base and subbase layers

Salt can react with the compounds in aggregates forming crystals of different chemical compounds that will increase in size which may result in the cracking of aggregates and a change in the 'grading' of the granular material. In addition, this disintegration may reduce the aggregate interlock and/or increase the plasticity and therefore, reduce the overall strength of the material.

The appearance of eruptions of small blisters in a bituminous treatment can indicate the presence of salt in the base material. The RTA surfacing guide recommends that a base material suspected of having a high salt content should be tested in accordance with Test Method T200 (RTA, 2002). For treatments of base materials containing various levels of salt in the uppermost level of the surface, the suggested treatments are listed in Table 2.

5.3.2 Modified and bound materials

There is still some confusion over how to define modified and bound pavement materials. To address this concern, a recent draft edition of the Austroads guide to stabilisation (Austroads, 2004c) has refined the existing definitions and these are summarised in Table 3. In Australia, modified materials are mainly constructed insitu using one of the many chemical binders on the market (Vorobieff, 2004) and in particular, dry powdered polymers which have been used extensively in the saline areas of south western NSW (Lacey, 2004 and Vorobieff, 2001).

Table 3 Proposed classification of stabilisation materials for Austroads guide (Austroads, 2004c).

Type of Stabilisation	Typical binders adopted	Performance attributes
Granular 40% < CBR < +120%	Blending other granular materials which are classified as binders in the context of this Guide.	Flexible pavement subject to shear failure within pavement layers and/or subgrade deformation
Modified 0.7 MPa < UCS* < 1.5 MPa	Addition of lime. Addition of polymer or chemical binders.	Flexible pavement subject to shear failure within pavement layers and/or subgrade deformation. Can also be subject to erosion by water penetration through cracks.
Lightly Bound 1.5 MPa < UCS* < 3.0 MPa	Addition of small quantities of cementitious binders. Addition of small quantities of bituminous or bituminous/cementitious binders.	Lightly bound pavement which may be subject to tensile fatigue and/or subgrade deformation. Can also be subject to erosion by water penetration through cracks.
Bound UCS* > 3.0 MPa	Addition of higher quantities of cementitious binder. Addition of a combination of cementitious and bituminous binders.	Bound pavement subject to tensile fatigue cracking and transverse drying shrinkage cracking. Less likely to be subjected to erosion by water penetration through cracks.
Note: UCS test specimen prepared using standard compactive effort and 28 day normal curing.		

As noted in this paper, bound materials assist by reducing water entering the subgrade and preventing the water table from rising. However, shrinkage or environmental cracking must be sealed after it appears, by crack sealing or using SAMI or crumbed rubber seals that allow the sealing of cracks. Layers of asphalt over bound subbases also provide a suitably strong pavement structure and reduces water penetration into the subgrade.

No technical evidence has been found by the author to confirm the exact effect which salt has on the strength of stabilised layers using cementitious of bituminous binders. Australian research is required to establish the loss in strength as a result of using these binders at various salt levels.

5.3.3 Insitu concrete

Concrete roads are commonly used in NSW. In new estates, some streets have bus stops and traffic calming sections constructed from reinforced concrete. To date, concrete roads constructed well, have not shown deterioration from salinity. As an example, Foreshore Road at Botany Bay adjacent to the bay was built in 1979 with continuous reinforcement and there are no signs of steel corrosion distressing the pavement (see Figure 7).

Concrete road in western Sydney provides a heritage look.	Foreshore Road, Botany carries heavy traffic to Botany Container Port Terminal.

Figure 7 Local street and major road constructed in reinforced concrete.

One area that designers may need to consider for local concrete roads that may be affected by salinity, is contraction joint forms using steel. These materials may or may not be galvanised, but their exposure to saline water is likely to render them inoperative should they corrode. Thicker pavements and epoxy coated tie bars may be required to ensure the concrete reaches its design life of 40 years.

5.3.4 Permeable concrete segmental paving

The 1990s saw the introduction of permeable concrete eco-paving into Australia and this pavement structure concept is strongly promoted by the Concrete Masonry Association of Australia[6] (Shackel, 2003). The use of the permeable concrete segmental pavement system is based on:

- on-site retention of rainwater,
- control of the discharge water,
- control of the discharge water quality,
- limits of the extent of impermeable areas,
- measures to reduce sedimentation and/or pollution.

[6] The Concrete Masonry Association of Australia web site address is www.cmaa.com.au

A system has been developed for both the infiltrated water to flow into the subgrade and for water to be contained into a subsurface catchment as shown in Figure 8. However, the latter system needs careful consideration of its maintenance requirements should the roadway be trenched after construction and of how construction traffic is managed during the construction of a new estate.

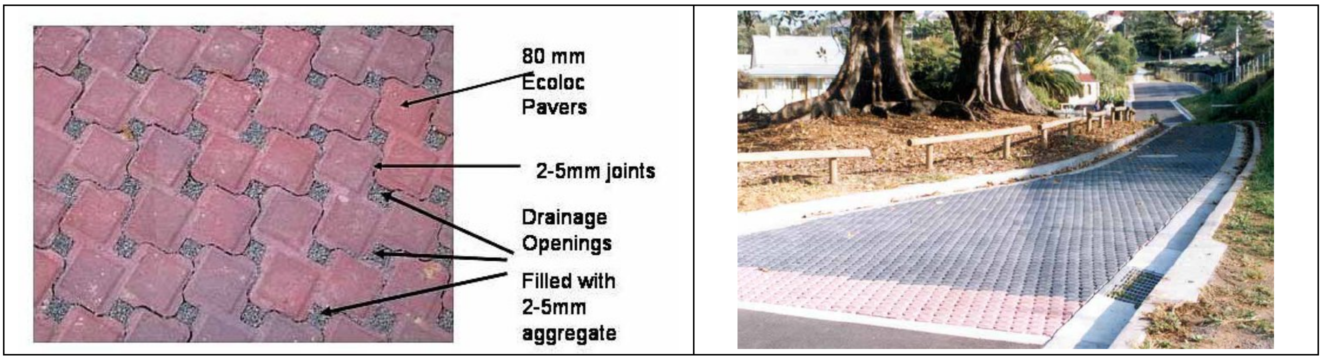

Figure 8 Permeable concrete eco-paving using concrete segmental pavers.

5.3.5 Subgrade materials

The typical properties sought from subgrade materials are:

- unsoaked and soaked strength in terms of CBR
- Plasticity Index
- potential for swell
- permeability

Subgrade materials that are considered expansive are shown in Table 4. Engineers who fail to address expansive soils may experience loss of pavement shape during seasonal moisture changes.

Table 4 Guide to the classification of expansive soils (Austroads, 2004b).

Expansive Nature	Liquid Limit (%)	Plasticity Index	PI x % < 0.425 mm	Potential Swell (%)*
Very high	>70	>45	>3200	>5.0
high	>70	>45	2200 – 3200	2.5–5.0
moderate	50 – 70	25 – 45	1200 – 2200	0.5–2.5
low	<50	<25	<1200	<0.5

The strength of subgrade materials will dictate the thickness of base and subbase layers, and whilst bound materials may be used to reduce the overall pavement thickness, a good subgrade reduces the risk of early distress in pavement materials. Early distress in terms of rutting or cracking may cause further infiltration of water into the subgrade leading to a rising water table.

The permeability of subgrade materials is subject to the type of soil as shown in Table 1. Soils that have a high permeability will allow water to pass through and charge the water table. On the other hand, soils that have low permeability are likely to concentrate water and also concentrate salts. If the water table is rising due to water from road runoff, the provision of a low permeable subgrade layer at formation level would assist; provided that subsurface drains are present at the edges of the formation to remove the water present on the upper layer of the formation.

5.4 Kerb and gutters

Salinity damage to kerb and gutters is occurring where urban salinity has been identified, however there are simple solutions to resolve this issue. A typical strength of kerb concrete is 15 MPa compared to highway pavements constructed of concrete with a 28-day strength of 32 MPa. Another difference is that extruded and externally vibrated concrete is unlikely to reach its maximum density compared to the slipformed process used for major concrete roads. Council engineers need to increase the standards for the concrete and construction process for kerb and gutter in regions affected by salinity; otherwise programmed replacement of kerb and gutter will be inevitable. Refer to work by the Cement Concrete Aggregates Association on recommended practices (CCAA, 2005).

5.5 Lime stabilisation with wet and salty conditions

Many of our pavement failures can be attributed to wet and or weak subgrades. Methods to improve a subgrade and to allow construction on soft subgrades include the following (Austroads, 2004b):

- draining and drying of the subgrade,
- excavation and replacement of soft material with stable material,
- provision of a gravel or rock fill working platform covered by an impermeable capping layer,
- stabilisation of the top layer of the subgrade,
- provision of a working platform of cemented material,
- provision of a lean concrete working platform,
- use of geotextiles.

The above suggestions need to take into consideration the limited opportunity to provide substantial cover in new estates. Geotextiles may also interfere with the use of underground services.

When designing pavements with a subgrade CBR less than 3% at the time of construction, the effect of subgrade improvement by insitu stabilisation using small application rates of lime or cement to allow construction to proceed is usually ignored and a design CBR of 3% is adopted at the new subgrade level. More substantial structural improvements to a very weak subgrade may be utilised by using design procedures adopted by Austroads (Austroads, 2001) and AustStab (Vorobieff, 2003, AustStab, 2004).

Both quicklime and hydrated lime is used for subgrade stabilisation of clays to:

- increase subgrade stiffness,
- reduce the PI of insitu pavement material,
- enhance volumetric stability for the top layer of select material,
- modify subbase layers to improve stiffness of the pavement, and
- produce a temporary construction platform for civil works.

Hydrated lime in the presence of water sets up an alkaline environment (pH > 7) in which the lime will react with any pozzolans[7] that are present in the pavement material or subgrade. This chemical process is at work in road stabilisation projects where clays provide the siliceous and aluminous components of the soil. Small quantities of organic material are likely to reduce the effectiveness of this chemical reaction.

The lime's reaction with the soil is two-fold. It firstly agglomerates fine clay particles into coarse, friable particles by a base exchange with the calcium cation (of the lime) displacing sodium or hydrogen ions with a subsequent ‘dewatering’ of the clay. Secondly, the lime raises the pH to above 12, which encourages chemical reactions that lead to the formation of calcium silicates and aluminates.

These calcium complexes initially form as a gel which coats and binds soil particles as the chemical processes move toward the crystallisation (cementitious) stage as they form hydrates. The rate of crystallisation is temperature dependent and may take many months to reach completion. This in turn correlates to a steady strength gain that can be tracked and measured using the CBR test.

If subgrade materials are subject to seasonal variations in moisture and the material is known to swell and shrink, the cracks that appear in the subgrade are likely to propagate into the pavement materials or footpath leading to more water getting into the subgrade. Lime stabilisation will generally remove this effect by binding the subgrade material and reducing its sensitivity to changes in moisture.

Studies by Stocker at ARRB in the 1970s concluded that when modification of the soil was very strong, a decrease in permeability was produced (Stocker, 1972). If water entry into the material can be reduced, the opportunity for salt to be diffused into the material and reducing the subgrade strength is diminished.

As always best practice mixing is required to ensure that the lime is thoroughly mixed into the pavement material and the reaction has sufficient time to take place with a minimum of two pass mixing (Austroads, 2003a and AustStab, 2004)

Lowering of permeability
For the soil studied, when modification was very strong a decrease in permeability was produced. This was concluded to result from occlusion of narrow voids by a reaction product developed only at very advanced stages of modification. This occlusion of voids which strongly impedes transport of water makes little difference to the ease of diffusion of lime through the water filling the clay matrix voids. In less modified soil there may be an apparent reduction in permeability, due to prohibition by cementation, of swelling during the permeability test.
(Stocker, 1972)

6 CONCLUSIONS

Previous work by others note the following methods to withstand the effects of salinity:

- raise the existing pavement level with suitable material and stabilise the top layer/s to strengthen the material to carry heavy traffic,
- stabilise the subgrade to reduce susceptibility to moisture changes,
- design subsurface drainage systems, and
- extensive planting of trees in the road reserve to bring down the water table.

[7] Materials containing reactive silica and alumina.

A major cause of salinity damage at the road surface is the rising water table carrying salt. Keeping the pavement area under an 'umbrella' will limit water penetration into the subgrade and hence the water table. Subsurface drains should be appropriately located and sized to carry moisture out of the pavement area. Porous surfaces such as segmental paving should not be used in these areas.

Lime stabilisation of subgrades dries out the subgrade and also reduces the permeability and prevents cracking due to seasonal moisture changes leading to less water entering the water table. Best construction practice will ensure that lime will be sufficiently mixed and react with soils for long term strength and low permeability. There is no known evidence that salt will degrade the lime stabilised materials.

A key finding in this paper is that standard construction practices may be insufficient for roads in salinity affected areas. For example,

- The use of standard extruded concrete kerb and gutter mix is insufficient to cope with the aggressive nature of saline water/moisture. Higher concrete strength and better compaction is required.
- Salt may crystallise under sprayed seals when constructed on fine crushed rock base material, resulting with the seal 'blowing up' which would lead to a pot hole in the road if not treated.
- Poor or no subsurface drainage will allow water to pond on the surface and increase the eventual charging of the water table.
- The use of recycled materials or crushed sandstone with high levels of permeability allows water to pass into the subgrade and weakens the road structure when supported on weak and wet subgrades.

Similar to the work by ARRB in Wyndham City, engineers need to raise the standards of design and construction in saline prone areas to ensure long-term durability problems do not become a liability on the competing use of rate payer funds. Alternatively, Councillors need to work with the community to limit housing and industrial development in salinity effected areas.

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