THE USE OF SEAWATER IN ROAD CONSTRUCTION: PART 3 – A QUICK GUIDE TO AN ACCELERATED CONSTRUCTION METHOD

F NETTERBERG

Pavement Material & Geotechnical Specialist, 79 Charles Jackson Street, Weavind Park, Pretoria 0184, South Africa; Tel: 012 846 7051; Email: frank.netterberg@gmail.com

ABSTRACT

The usual South African requirement for the maximum soluble salt content of the base and subbase of a road to be covered with a bituminous surfacing as determined by the paste electrolytic conductivity (EC) test of 0,15 S/m is a conservative limit intended for normal use without requiring any special design or construction precautions. Compaction of most pavement materials with an inherently low EC of less than about 0,1 S/m with seawater or other comparable chloride-sulphate water with a salinity of about 3,5% will raise the EC to about 0,5 S/m, which exceeds even the maximum of 0,40 S/m usually specified for selected subgrade layers. A design and accelerated construction method was therefore developed from experience and research in order to enable the use of both inherently saline materials and waters with a salinity up to about that of seawater for compaction with little risk of salt damage. This essentially involves covering each layer with the next as soon as practicable in order to minimise upward migration during construction and then priming and sealing the base as soon as practicable with an impermeable surfacing in order to keep the salt safely in solution. The maximum target delays between the pavement layers derived from local experience and LTPP experiments together with additional precautions are summarised, together with comments on evaluating water for road compaction.

1. INTRODUCTION

The usual (e.g. Committee of Land Transport Officials (COLTO), 1998) requirement for the completed base and subbase of a State road with a flexible pavement to be covered with a bituminous surfacing of a maximum saturated paste electrolytic conductivity (EC) of 0,15 S/m determined according to TMH1:1986 Method A21T (National Institute for Transport and Road Research (NITRR),1986a) is a conservative limit intended for normal use without requiring any special precautions and in order to allow a layer – and especially a primed base course – to stand for some time (possibly weeks to months) with little risk of salt damage due to crystallization of the salt.

The current national draft (but legal) South African specifications for road construction water Committee of Transport Officials (COTO), Oct. 2020) limits the total dissolved solids (TDS) content of compaction water to a maximum of 1 200 mg/ℓ (0,12%) for crushed stone base course and stabilized materials and 2 400 mg/ℓ (0,24%) for other layers and materials. However, consideration of the use of brackish and even seawater is permitted provided that the saline water is used for the EC and pH tests and that the limit of 0,15 S/m of COLTO:1998 and COTO:2020 is not exceeded without expert advice and proved in a trial section.

ISBN: 978-0-6397-8659-9
Pretoria, South Africa
Produced by: www.betaproducts.co.za
Conference Proceedings

Compaction of most pavement materials with an inherently low EC of less than about 0,10 S/m with seawater or other comparable chloride-sulphate water with a salinity of about 3,5% will raise the EC to about 0,5 S/m, which exceeds even the maximum of 0,40 S/m specified for selected layers.

Owing to the typical requirements of upwards of 1 000 m^3/day for compaction and other purposes combined with the general scarcity of freshwater over most of southern Africa, an accelerated construction method was therefore developed from both local experience dating as far back as the 1960s and purpose-built experimental sections (Netterberg 2022a, 2023 a, b) in order to enable the use of both inherently saline materials and waters with a salinity up to approximately that of seawater for the compaction of unstabilized materials with little risk of salt damage.

The principle of the method is simply to prevent crystallization of the soluble salt by sealing in sufficient compaction water to keep the salt safely in solution. This essentially involves covering each layer with the next as soon as practicable in order to minimise drying and upward migration during construction and then priming and sealing the base with an impermeable surfacing as soon as practicable after compaction (Netterberg, 1983).

Guidelines according to the same principles have been used in Australia (e.g. Januske & Booth, 1992; Australian Asphalt Pavement Association, 2008; Cocks et al., 2015), Botswana (Obika, 2001) and elsewhere and have been reviewed by Netterberg (2022a). However, owing to the different salt test methods and, in the case of Australia the bituminous binders and seals employed, exactly the same guidelines cannot be used here.

The “G” material quality and state classification referred to is that of COLTO:1998.

Although this protocol was developed for untreated pavements, more limited experience indicates that the same principles can be used for cement and lime stabilized layers provided that they comply with the durability, salt and pH requirements of COLTO:1998 or COTO: 2020 and TRH13:1986 (National Institute for Transport and Road Research (NITRR), 1986b) as appropriate, and that only freshwater (if any) is used for curing.

2. MAXIMUM TARGET DELAYS BETWEEN LAYERS

The following target delays assume an EC of the full thickness of the layer after compaction of up to 1,0 S/m but are conservative guidelines rather than specifications as both the risk of and the time before damage occurs also depend upon the season, weather and the particular material, and should be varied according to the measured EC – the higher the EC, the hotter, drier and windier the weather and the finer the grading the sooner the likelihood of damage and the shorter the delay allowable. Finer-grained materials – especially calcretes – are more liable to salt damage than coarser and also require more water for compaction

2.1 Delay Between Earthworks Layers

Cover each layer as soon as practicable with the next layer even if only by dumping and spreading. However, do not delay it unnecessarily and aim for the same target delays as for the subbase.

2.2 Delay Between Subbase and Base

The maximum target delay recommended between a G6, G5 or G4 subbase and completion of the base is four weeks for an EC of 0,16 – 0,25 S/m, three weeks for an EC of 0,26 – 0,50 S/m and two weeks for an EC exceeding 0,50 S/m.

2.3 Delay Between Base and Priming

The maximum target delay recommended according to the EC just after completion of the base and priming with a cutback or invert emulsion primer at about 0,7 ℓ/m^2 is:

EC (S/m)	G4 - G6	G2 or G3
0,16 – 0,25	14 days	30 days
0,26 – 0,50	7 days	14 days
0,51 – 1,0	2 days	14 days

2.4 Delay Between Priming and Sealing

The maximum target delay recommended according to the EC just before priming between priming and surfacing is:

EC (S/m)	G4 - G6	G2 or G3
0,16 – 0,20	7 days	30 days
0,21 – 0,30	48 hours	21 days
0,31 – 0,60	24 hours	14 days
0,61 – 1,0	6 hours	7 days

3. ADDITIONAL PRECAUTIONS

The basic principle is to cover each layer with the next as soon as practicable, even if only by dumping and spreading it loosely to act as a mulch. It should preferably not be trafficked.

Use as coarse a grading as permitted by the specifications, especially for the base course, and avoid slushing if possible.

The base must be thoroughly swept of excess fines to as a good mosaic as possible before priming and the use of a dampening spray of even freshwater avoided if possible. If necessary the primer should be omitted and the emulsion tack coat of the seal applied at a higher rate, especially on a G4, G5 or G6 calcrete base with an EC of more than about 0,5 S/m. The construction of trial sections is recommended.

The presence of salt will extend the drying time of a primer.

It is better to delay the priming rather than the sealing as rain on a primed base with an EC of more than about 0,5 S/m may cause immediate prime damage on drying, especially on a calcrete. Although this may conflict with the contractor’s insurance conditions, light rain on an unprimed layer may actually be beneficial and leach out some of the salt or drive it downwards.

The use of a heavier primer and/or at an increased rate may extend the period of time between priming and the onset of damage but will of course also extend its drying time.

At an EC of about 0,5 S/m or more the surfacing should be a double seal with a fog or a 19 mm Cape seal with two hand-spread and well-rolled slurries, in preference to asphalt, and designed according to the traffic expected to be impermeable and as rich as possible without excessive bleeding. Asphalt should be well compacted to as low a percentage of air voids as possible without the risk of excessive bleeding, shoving or rutting.

The surfacing aggregate must be of high quality with a minimum of dust and soft or weatherable particles which might result in stripping and even holes, especially on highly saline calcrete gravel bases, which are liable to develop into potholes.

The surfacing must be thoroughly rolled over its full width with a pneumatic roller and opened to traffic as soon as possible, if necessary continuing the rolling until opening.

Sealing the shoulders with the same seal and not just a single or a slurry should be considered at an EC of about 0,5 S/m or more on any base or the provision of a thickened edge to a calcrete base.

As most of the salt remains within the pavement the success of this technique is reliant upon maintaining a water content of at least about 2 %, reasonable maintenance, and the preservation of surfacing integrity in order to prevent excessive drying of the upper base, and the consequent development of blisters, ridged cracks or edge breaking.

The surfacing of a base with an EC exceeding about 1,0 S/m or the presence of a shallow water table, especially if it is saline, adds additional risk and requires additional precautions such as control of the surfacing permeability to air and/or the provision of a cut-off membrane, which are not discussed here.

4. REPAIR OF SALT-DAMAGED SURFACES

Damage to an unprimed layer usually takes the form of white staining, glazing, or a loss of density of the upper 10 – 20 mm due to crystallization of the salt on drying out. In rare cases the upper 50 mm or more can be affected. Such damage can simply be watered and recompacted. The following layer should then at least be dumped and spread without delay to act as a mulch. Should the layer exceed the EC permitted by the specifications, it can be sampled in 25 or 50 mm increments, sufficient cut off to return it to specification, and the thickness made up by the following layer.

Should damage to a primed surface occur it should be well swept, any hollows patched, reprimed and/or the spray rate of the emulsion tack spray increased if necessary, and sealed as soon as possible thereafter.

In the absence of a shallow salt water table such damage does not usually lead to surfacing damage but may result in some loss of smoothness. In such cases a Cape seal is preferable to a double seal.

The loss of any prime overspray and some of the slurry overspread to the edge of a Cape seal is likely at ECs in excess of about 0,2 S/m and significant surface looseness of an unsealed shoulder and/or edge fretting at ECs above about 0,5 S/m. The former are usually acceptable, but the edge fretting may require extra maintenance.

The prevention and repair of severely blistered and cracked salt-damaged surfacings is best achieved with a bitumen-rubber reseal rather than a conventional seal or asphalt (Netterberg & Bergh; 2019; Netterberg, 2022b), and the prevention of severe edge fretting by means of a thickened edge.

5. EVALUATING WATER FOR COMPACTION

5.1 Introduction

All of the following tests will seldom be required, and each case must be considered on its own, bearing in mind the time available, the degree of certainty required, and whether testing the combined effect of the material and the water is necessary (recommended) or the effect of the water alone is to be isolated.

Aspects which should be considered are:

a) Engineering: efflorescence, surface disintegration, loss of density, blistering, edge fretting, staining, corrosion, compactability, strength, density and durability.
b) Environmental: possible effect on health and safety of workers and all life (not treated here).

No discussion of these problems can be presented here, for some of which see Netterberg (2022a) and the references therein. It is the purpose of this note simply to suggest those tests which should be considered. The chemical tests should be regarded as indicative and the physical engineering tests and road trials as more definitive.

5.2 Chemical Tests

The salts present in waters and road materials have been reviewed by Netterberg (1970, 2022a).

The following should be determined according to the source and proposed use of the water:

Apparently non-polluted waters: as for the proposed use. Guidelines for sampling (Department of Water Affairs and Forestry (DWAF), 2000) and the analytical requirements and their interpretation for various purposes such as for domestic and other uses are provided in the DWAF series of South African water quality guidelines such as DWAF (1996) for industrial use, e.g. dust suppression, firefighting, vehicle washwater, etc., the risk of corrosion or scaling of equipment, and the disposal of any wastewater.

Treated effluent and other waste or possibly polluted waters: as for compliance with the General or Special effluent standard (Department of Water Affairs (DWA), 1999) as appropriate and also as for the proposed use.

As many treatment works are dysfunctional (Wall, 2018) treated effluent must be tested on a regular − possibly even daily − basis including for the health and safety requirements.

Use of EC instead of TDS: Although COTO:2020 and most other guides and specifications usually list both a total dissolved solids (TDS) as well as an EC requirement, the two are closely related and for most natural waters the following average factors can be used:

$$TDS = 6{,}5\ EC \text{ where TDS is in mg/l and EC is at 25°C in mS/m (DWAF, 1996)} \quad (1)$$

or

$$TDS = 0{,}65\ EC \text{ where TDS is in \% m/v and EC is at 25°C in S/m} \quad (2)$$

The factor 6,5 varies between 5,5 and 7,5 (DWAF, 1996) and should be determined for the specific water where the greatest accuracy is required.

The same factor of 0,65 EC in S/m can be used for seawater within the usual range of 3 and 4% to estimate the TDS on a m/m basis. For more accurate work on seawater or other similar chloride-sulphate waters Figure 5 of NITTR Test Method CA21-74 (1980) or factors derived from it can be used.

The accuracy of this simple EC conversion method is probably about ± 10% of the TDS in the case of natural waters of unknown composition and much better in the case of seawater. This is adequate for most road works and the difference between the TDS expressed as m/m (as is usual for seawater) and m/v is also usually of little concern.

The use of EC alone, which is quickly and easily determined in a site laboratory or even at the source, is therefore usually adequate.

An hydrometer reading from 0 to 5 or 6 degrees heavy Baumé (Bé), which are closely equal to the TDS on a m/m basis (Weast, 1977) can also be used, and pocket EC and pH meters are also available.

For compaction of untreated materials: EC, TDS and pH (COTO:2020)

For compaction and curing of cement or lime-treated materials: EC, TDS, pH and sulphate (COTO: 2020).

Seawater has been successfully used in the **slurry** of a Cape seal (Netterberg, 2004).

For graded crushed rock, gravels and soils use the TMH1:1986 A21T saturated paste EC (NITRR, 1986a) and **saturated paste pH (NITRR CA21-1974, 1980) test methods** on the air-dried, dry-screened fraction passing 6,7 mm. The qualitative test methods for chlorides and sulphates described can also be used for water. For materials to be treated with cement or lime also follow the guidelines in TRH13:1986. Use these methods until the proposed new SANS 3001 series methods are available and have been shown to be equivalent. Do **not** use the old SANS methods or theTMH1:1986 A20 pH method.

Up to an EC of about 1,5 the EC in S/m of a material is approximately numerically equal to the percentage NaCl or sea salt in the minus 6,7 fraction (NITRR CA21-1974:1980).

Gypsum is not deleterious in untreated materials not subject to leaching (Netterberg, 2021) but can be in cement and lime treated materials, especially under wet conditions.

Testing for pH as well as EC is also recommended at least at the design stage and at each change of water or material as pHs outside the usual range of about 6,0 – 8,2 suggest the presence of some unusual component and warrant further consideration.

So-called ‘**salt roads’** have been used along the desert coast of Namibia mostly in the Swakopmund area for many years (Bravenboer, 2011) as a dust-free, economic alternative to bituminising. They are essentially unsealed gravel roads with a wearing course of plastic, saline, gypcrete gravel compacted with salt water and yield excellent performance except when it rains, which is seldom. Seawater is insufficiently saline for this purpose and waste brine from the coastal salt works or salt water from a salt pan is used. The use of such waters results in severe corrosion of roadmaking equipment, especially tankers, as well as vehicles using these roads.

A minimum TDS of 18% in the compaction water is specified for the upper 50 mm of the wearing course and 8% for the lower 100 mm (Roads Authority, 2014). Research by the author together with the local maintenance unit indicated that water with 11% salt was the worst usually used, 22% gave good results and 24 – 29% very good results. However, the best water could simply be obtained by excavating a hole on the edge of a salt pan and waiting for the water to exhibit crystallization of salt. The salt content of such a water is around 26% m/m. The salinity of the water is easily determined on site using an hydrometer graduated in up to 30 degrees heavy Baumé which from Weast (1977) is approximately equal to the salt content in % m/m. A lead-acid battery hydrometer can also be used: water containing 11% m/m salt has a specific gravity of 1,08, 18% 1,13 and 26% 1,20 at 20°C. For the most accurate work a temperature correction must be applied to both types of hydrometer.

No attempt should be made to apply any kind of bituminous surfacing to a salt road without expert advice.

5.3 Engineering Tests

The presence of salts such as gypsum ($CaSO_4{\bullet}2H_20$) with bound water will result in overestimation of the free water content by both nuclear and oven-drying (at 105 – 110°C) methods and the consequent overestimation of the LL PI, and optimum water content (OWC) and underestimation of the dry density and relative compaction. Although the amount of this effect can be calculated theoretically, it does not appear to have been experimentally confirmed.

Salts containing chlorine such as NaCl will cause a nuclear gauge to underread the free water content and thereby overestimate the dry density and relative compaction. The amount of such salt necessary to have a significant effect appears to be unknown.

As in concrete technology, as a general rule it is best to **t**est the proposed material with both the proposed water as well as the water prescribed for the test.

Although COTO:2020 requires that the tests for EC and pH shall be carried out with the proposed saline water instead of the prescribed distilled water, a more accurate simulation may be to determine the EC and pH with distilled water after adding the estimated amount for compaction and also slushing or curing if appropriate and allowing for every extra that might be added to allow for evaporation, etc., to the whole grading before air-drying and screening out the < 6,7mm fraction for the test. This is obviously more work.

Should natural seawater not be conveniently available substitute seawater can easily be made up (e.g. according to ASTM D1141) with the omission of the unnecessary minor components. This can also be diluted to make up typical chloride-subphate waters of lower salinities.

5.3.1 Efflorescence

Efflorescence, surface disintegration, superficial loss of density and strength, staining and blistering of primed surfacings are the most common types of salt damage and probably best evaluated by means of simple model experiments in CBR moulds (Netterberg & Loudon,1980; Jones & Netterberg, 1999). **Prevention** of this kind of damage is best achieved by limiting the EC of the finished layer and applying construction time constraints as outlined in Section 2. Edge fretting may or may not be accompanied by blistering.

The ASTM 67 efflorescence test for brick and tiles – and for concrete (Suprenant, 1992) – can probably also be applied to UCS specimens of cement stabilized material.

5.3.2 Compactability, Strength and Density

A general protocol for the determination of the working time for cement-treated materials is available from the Cement and Concrete Institute in Midrand. This can be followed by means of comparative testing using the proposed water and if necessary the prescribed water. These might include both the initial (IS) and final setting (FS) time of the proposed cement, the rate of early strength development using the CBR or UCS as convenient and its effect on density

The purpose of the above testing is to determine beforehand whether the water-material combination is likely to accelerate the setting or hardening of the mix and thus cause compaction problems (e.g. lower density and/or strength, and degradation and/or shearing of the upper part of the layer).

5.3.3 Durability

Comparative testing with the proposed water can also be carried out using the wet-dry brushing test. If it is also desired to use the proposed water for curing, then it should also be used for the wetting cycles. If not, then the good water should rather be used for wetting. UCS, density and PI tests after extended soaking (TRH13:1986) if excess sulphates or clay is suspected, accelerated carbonation, and an ICL/ICC test should also be considered.

6. CONCRETE

The water requirement for Portland cement concrete on a road project is usually small other than for concrete pavements and is not considered here in any detail, for which see Roxburgh (2021).

Potable water is almost always suitable and used, although brackish, salt and even seawater can be used in plain concrete without reinforcement or other embedded metal. Waste waters may also be suitable in all forms of concrete, and can be assessed using SANS 51008:2006/EN 1008:200 (Goodman, 2009). Efflorescence testing is always advisable.

However, conservative restrictions are usually placed even on the TDS for plain mass concrete in order to prevent any possible errors or problems such as efflorescence, and the COLTO:1998 and now COTO:2020 (which simply refers to SANS 51008) requirements are relevant for road projects. Only potable water should be used for curing.

7. DISCUSSION

Existing standards and procedures have been developed over many years and are deliberately conservative in order to cater for average conditions, workmanship, material variability, and degree of construction mishandling.

Departure from such standards and procedures usually adds increased risk to a project − both technically and of the question of responsibility.

Where conditions permit it is therefore always preferable to use freshwater even if it is not potable.

However, the construction time constraints and precautions outlined were also developed over many years on a number of projects as well as purpose-built experiments, discussed with road authorities, contractors and consultants, and similar procedures have been used elsewhere, all apparently with a high degree of success.

Any such departures from existing practice – especially time constraints − must of course be included in the Special Provisions at the tender stage and approved by the client.

Nevertheless, unexpected delays and other problems do occur and it is not always possible to comply with such departures, as happened for example in the case of the Sua Pan Airport (Netterberg & Bennet, 2004).

In particular, although possible, the time constraints at ECs above about 0,5 S/m are very onerous and consideration should be given to the omission of the primer, especially on calcrete gravel bases, and increasing the spray rate of the emulsion tack coat of the seal as was done successfully on the Kleinzee-Koingnaas road (Spottiswoode & Graham, 1982; Netterberg, 2022a, 2023c).

In the case of the 600 km Trans-Kalahari road approximately 86 boreholes were drilled to an average depth of 180 m, most of which proved to be brackish or saline and many of which exceeded even the salinity of seawater (Pinard et al., 1999). Instead of applying the stringent time constraints specified the contractors opted as far as possible to pump water from the non-saline boreholes and to store it in reservoirs along the road alignment. Salt damage apparently only occurred where the specified time constraints were not met.

Other methods which have been used locally to either avoid or reduce the use of saline water and any time constraints have included the use of a drybound macadam base, (Horak et al., 2011), block paving (Netterberg & Bennet, 2004), compaction at the lower (drier) of the two optimums possessed by some materials, surfactants, “dry” compaction, (e.g. Pinard & Ookeditse, 1988; Palmer et al., 1992), and simply the pragmatic acceptance and repair of slight damage to a primed base course or surfacing. Compaction at a low water content carries the risk of building in a collapsible grain fabric.

Provided that it does not drop below about 1 or 2 percent, priming and sealing a base course as soon as possible after compaction in order to prevent the crystallization of salt is not necessarily in conflict with the modern requirement (e.g. COLTO:1998) that no seal shall be placed before the water content of the upper 50 mm of the base in less than 50% of optimum. Sampling and testing for water content and EC in 50 mm layers is recommended.

Rapid sealing did result in some punching of the seal over a very small part (less than about 1%) of the Swartklip experiment (Netterberg, 2023a) but did not occur on the Lüderitz experiment (Netterberg, 2023b), on both of which G3 bases were used.

Health, safety, environmental and corrosivity aspects and any regulatory requirements with respect to the use of seawater on land may have to be considered.

The work on which this paper has been based has been limited to seawater and other chloride-sulphate waters and no soda carbonate waters (Bond, 1946) were included.

8. CONCLUSIONS

Seawater and other chloride-sulphate waters up to at least the salinity of seawater (about 3,5%) and relative composition can be successfully used for the compaction of all layers of a flexible pavement including a lime or cement stabilized base, but should not be used for curing such a layer.

Such use should not lead to any significant salt damage during or after construction other than a possible increase in edge fretting and shoulder surface looseness, or to a reduction in the structural capacity, provided that the design, construction and maintenance precautions discussed are taken.

These precautions essentially involve covering each layer with the next and surfacing as soon as practicable with an impermeable, flexible seal according to the salt content of the completed layer, as measured by the simple paste electrolytic conductivity test.

9. ACKNOWLEGEMENTS

This paper is mostly based upon reports by the author to the Roads Authority of Namibia and a report on the use of non-potable water in road construction (Netterberg, 2022a) to the Water Research Commission and is used with their consent. This report and the Roads Authority's (2014) materials manual should be referred to for further details. These guidelines are based both on the author's some fifty years of experience with the problem of salt damage and the use of saline and acidic materials over most of southern Africa and elsewhere, as well as on full-scale, long-term, road experiments (Netterberg 2023 a,b,c), the application of the preliminary findings (Netterberg, 1983) to the construction of a low volume road in an arid area (Spottiswoode & Graham, 1982; Netterberg, 2022a), and its long-term monitoring and evaluation (Netterberg, 2023d). Some of this work was carried out whilst the author was employed at the then National Institute for Transport and Road Research of the CSIR, Pretoria. However, the opinions expressed are those of the author and not necessarily any of the above.

10. REFERENCES

ASTM International. 2013. ASTM D1141-98 (2013) Standard practice for the preparation of substitute ocean water. Annual Book of ASTM Standards, 11.02, ASTM, West Conshohocken.

ASTM International. 2021. ASTM C67/67M-21: Standard methods for sampling and testing brick and structural clay tile. Annual Book of ASTM Standards, 04.05, ASTM, West Conshohocken.

Australian Asphalt Pavement Association. 2008. Sprayed sealing of drought- & salt-affected pavements. AAPA/AUSTROADS Pavement work tips No. 47, Sydney.

Bond, GW. 1946. A geochemical survey of the underground water supplies of the Union of South Africa. S. Afr. Geol. Survey Mem. 41, Govt Printer, Pretoria.

Bravenboer, B. 2011. History of the Namibian road sector. Roads Authority, Windhoek.

Cocks, G, Keeley, R, Leek, C, Foley, P, Bond, T, Cray, A, Paige-Green, P, Emery, S, Clayton, R, McInnes, D & Marchant, L. 2015. The use of naturally occurring materials for pavements in Western Australia. Australian Geomechanics, 50(1):43-106.

Committee of Land Transport Officials. 1998. COLTO:1998: Standard specifications for road and bridge works for state road authorities. S. Afr. Instn Civil Engrs, Yeoville.

Committee of Transport Officials. 2020. Draft Standard COTO:Oct.2020: Standard specifications for road and bridge works for South African road authorities. SANRAL, Pretoria.

Department of Water Affairs. 1999. Wastewater limit values applicable to discharge of wastewater into a water resource. Govt. Gazette No. 20526, 08 October 1999.

Department of Water Affairs and Forestry. 1996. South African water quality guidelines. 3 - Industrial use, 2nd Edn, DWAF, Pretoria.

Department of Water Affairs and Forestry, 2000. Quality of domestic water supplies. 2 - Sampling guide. Water Research Comm. Rep. TT 117/99, DWAF, Pretoria.

Goodman, J. 2009. Mixing water. In: Fulton's concrete technology (G Owens, Ed.) Cement & Concrete Inst, Midrand.

Horak, E, Emery, S & Walker, H. 2011. Novel measures to attenuate aggressive salt migration and crystallization on a Namibian airport runway project. Proc. 10th Conf. Asphalt Pavements Southern Africa, Champagne Sports Resort, 13 pp.

Januske, RM & Booth, EHS. 1992. Soluble salt damage to sprayed seals – prevention and maintenance. Proc. 16th Austral Road Res. Board Conf, Perth, Part 2, 173-189.

Jones, D & Netterberg, F. 1999. The potential for damage to primed bases and bituminous surfacings after using calcium chloride as a dust palliative during stage construction. Proc. 7th Conf. Asphalt Pavements Southern Afr., Victoria Falls, Theme 2, 74-80.

National Institute for Transport and Research, 1980. Determination of the electrical conductivity of and pH of a soil paste or water and qualitative tests for sulphate, chloride and carbonate or bicarbonate, NITRR Test Method CA-74 (1980), CSIR, Pretoria.

National Institute for Transport and Research. 1986a. TMH1:1986: Standard methods of testing road construction materials. NITRR, CSIR, Pretoria.

National Institute for Transport and Research. 1986b. TRH13:1986: Cementitious stabilizers in road construction. NITRR, CSIR, Pretoria.

Netterberg, F. 1970. Occurrence and testing for deleterious soluble salts in road construction materials, with particular reference to calcretes. Proc. Symp. Soils Earth Structures Arid Climates, Adelaide, 87-92.

Netterberg, F. 1983. Use of seawater and other highly saline waters for pavement construction: A preliminary report. NITRR Rep. RS/2/83, CSIR, Pretoria, 9 pp.

Netterberg, F. 2004. Use of seawater in the slurry of a Cape seal. Proc. 8th Conf. Asphalt Pavements Southern Afr., Paper 090, Sun City, 12 pp.

Netterberg, F. 2021. Gypsum in saline and non-saline road bases: Effects and limits derived from long-term road experiments in Namibia. Proc 39th Southern Afr. Transport. Conf., Pretoria, Session 2A, 15 pp.

Netterberg, F. 2022a. The use of non-potable water in road construction. Water Research Comm. Report No. 3035/1/22. WRC, Pretoria.

Netterberg, F. 2022b. Experimental rehabilitation of a road with intractable salt damage with a bitumen-rubber single seal. Proc. 40th Southern Afr. Transp. Conf., Pretoria, Session A, 17 pp.

Netterberg, F. 2023a. The use of seawater in road construction: Part 1 The Swartklip and Lambert's Bay experiments. Proc. 40th Southern Afr. Transport Conference, Pretoria, Session 1A, 16 pp.

Netterberg, F. 2023b. The use of seawater in road construction: Part 2 The Lüderitz experiment. Proc. 40th Southern Afr. Transport Conference, Pretoria, Session 1A, 15 pp.

Netterberg, F. 2023c. Performance of an experimental finely graded slightly plastic calcrete base course compacted with seawater over 30 years. Proc. 13th Conf. Asphalt Pavements Southern Afr., Champagne Sports Resort (submitted).

Netterberg, F. 2023d. Performance over 28 years of a low volume road with a coarsely graded plastic calcrete base course compacted with seawater. Proc. 13th Conf. Asphalt Pavements Southern Afr., Champagne Sports Resort (submitted).

Netterberg, F & Loudon, PA, 1980. Simulation of salt damage to roads with laboratory model experiments. Proc. 7th Reg. Conf. Afr. Soil Mech. Fndn Engng, Accra, 1:355-361.

Netterberg, F & Bennet, RA, 2004. Blistering and cracking of airport runway surfacing due to salt crystallization. Proc. 8th Conf. Asphalt Pavements Southern Afr., Sun City, Paper 088, 19 pp.

Netterberg, F & Bergh, AO, 2019. Rehabilitation of salt-damaged surfacing with bitumen-rubber and other seals. Proc. 12th Conf. Asphalt Pavements Southern Afr., Sun City, 11pp.

Obika, B. 2001. The prevention and repair of salt damage to roads and runways. Botswana Roads Dept Guideline No. 6, Gaborone.

Palmer, WT, Viljoen, DP & Van der Walt, N. 1992. The compaction of Kalahari sand at in-situ moisture content. Proc. 12th Ann. Transp. Conv, Pretoria, 2C, 19 pp.

Pinard, MI, Obika, B, Nkaro, A & Motswagole, KJ. 1999. The Trans-Kalahari Road project – An overview of innovations in planning design and construction. Proc. 7th Conf. Asphalt Pavements Southern Afr., Victoria Falls, 19 pp.

Pinard, MI & Ookeditse, S. 1988. Evaluation of high energy impact compaction techniques for minimising compaction water requirements in semi-arid regions. Proc. 14th Austral. Road Res. Board Conf., Part 7, 121-138.

Roads Authority. 2014. Materials manual. Roads Authority, Windhoek.

Roxburgh, J. 2021. Mixing water. In: Fulton's concrete technology (M Alexander, Ed). Cement & Concrete SA, Midrand.

South African Bureau of Standards 2006. SANS 51008:2006 EDITION 1EN 1008: 2002 Edition 1. Mixing water for concrete – specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete. SABS, Pretoria.

Spottiswoode, BH & Graham, RWV. 1982. Design & construction of a low-cost road at the West Coast. Proc. 1st Ann. Transp. Conv., Pretoria, 3, Session H, 26 pp.

Suprenant, BA. 1992. Efflorescence: minimizing unsightly staining. Concrete Constr. March, 240-243.

Wall, K. 2018. The evolution of South African wastewater effluent parameters and their regulation: A brief history of the drivers, institutions, needs and challenges. J. Trans disciplinary Res. Southern Africa, 14(1):a581. Available at: https://doi.org/10.4102/td.v14i1.581, 11 pp.

Weast. RC. (ed). 1977. CRC Handbook of chemistry and physics. 58th Edn, CRC Press, Cleveland, p. D-249, 253, F-3,4.