Use of Non-Potable Water in Pavement Construction: A Laboratory Study using Seawater

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ABSTRACT: The Intergovernmental Panel on Climate Change (2018) projects that global warming is likely to reach 1.5°C above pre-industrial levels between 2030 and 2052. The effect of climate change on warmer temperatures and longer lasting drought periods has been well documented in Southern Africa. The Global Disaster Alert and Coordination System (2020) has declared an orange level (intermediate impact) drought for 6 months in South Africa and Lesotho making them water scarce countries. Construction processes rely on the use of potable water. In road construction, the moisture content is an important factor that affects the density of a road material. Due to the limited research in South Africa on use of non-potable water in road construction, there has been a greater need to conduct laboratory research. This paper highlights research through laboratory testing of granular sub-base material mixed with seawater obtained from the Indian Ocean. Aggregate originating from dolerite, tillite and sandstone rock quarries were used. Potable tap water was used as a baseline to the tests. Promising results are showed in the laboratory testing and it is advisable that further research is required going forward.

1 BACKGROUND

Construction processes rely on the use of potable water. In road construction, the moisture content is an important factor that affects the density of a road material. An average of 50 litres of potable water per cubic meter of granular pavement material is required for road compaction. Given that South Africa has a network of over 22 000 km of roads, there is a need to re-evaluate the use of potable water in roads as the resource will be more beneficial to serve local communities in the future.

Climate change is contributing to the observed increases in longer lasting drought periods and warmer temperatures. The National Climate Change Adaption Strategy published by the Department of Environmental Affairs in the Government Gazette (2019) highlights the projected future changes in Climate in South Africa.

2 LITERATURE REVIEW

2.1 *Status of water in South Africa*

The Department of Water and Sanitation (South Africa) has published a situation report on the status and drought regarding water in the Western Cape (DWAS, 2018).

- South Africa is an arid country and one of the 30 driest countries in the world.
- The country as a whole has not recovered from the 2014 drought, with the Western Cape Province experiencing the worst drought in 400 years.

2.2 *The impact of climate change in pavement construction*

Climate change is contributing to the observed increases in longer lasting drought periods and warmer temperatures. Figure 1 depicts the projections for surface temperatures and rainfall until 2099 (Meehl et al., 2007). It can be seen that the mean surface temperature is between 3 and 5 degrees over the next hundred years. The different projections (B1, A1B and A2) are due to the variation in model co-efficient.

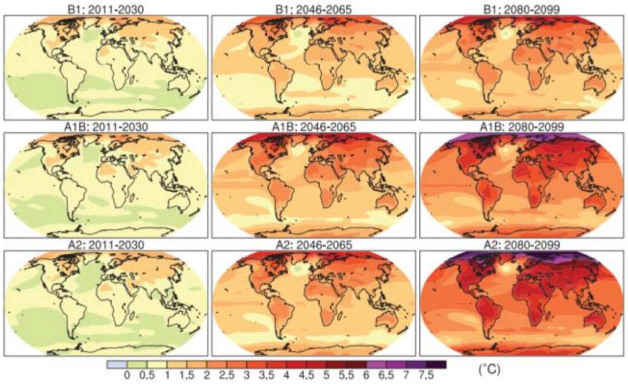

Figure 1: Multi-modal mean surface air temperature change projections (Meehl et al., 2007)

It is also noted that the mean rainfall patterns will decrease. The temperature and rainfall variations have a direct impact on the restriction of available potable water in South Africa.

2.3 *The use of non-potable water in pavement construction*

Large quantities of water are required for the compaction of pavement materials. In order to achieve optimum compaction, materials are usually compacted at or about optimum moisture content. This will usually be between 7 and 12 % of the mass of the material being compacted. In broad terms, this requires between 150 and 200 thousand litres of water per layer per kilometer, hence creating more strain on a scarce commodity. Although much of the water used in construction ultimately evaporates from the road and is returned to the earth's surface as precipitation, this is a long process and local depletion can occur rapidly, particularly in areas becoming drier through progressive climate change (Steyn and Paige-Green, 2009).

Netterberg (2004) investigated the use of seawater in pavement construction. Long-term experimental sections of a slurry seal made with seawater were used to complete a 19 mm Cape seal near Saldanha Bay, South Africa. Sections included seawater in both layers of slurry, in the top only, and in the bottom only, as well as control sections using fresh water. After 18 years under traffic, there was no significant difference between the performance of the sections made with seawater and those made with fresh water. It was concluded that the seawater used (3,2 % total salts, dominantly sodium chloride with some sulphate) can safely be used to make cationic slurries.

Netterberg (2013) also reported on experimental sections that were constructed in 1976 at Lüderitz on the arid coast of Namibia. The purpose was to develop methods of successfully using seawater for the compaction of all layers of a new road with a G3 base course under a Cape seal surfacing. These experiments have shown that, provided certain precautions are taken in the design and construction, seawater can be used in all layers including a G3 base course without experiencing any significant degree or extent of salt damage. The damage was not significant either during construction or in the long term, at least up to 36 years.

The effect of salt on bituminous pavements has been quantified by Shahin et al. (2015). In the study, 80/100 grade bitumen was used with aggregate and varying amounts of salt. The paper quantified:

- Material properties of aggregate and filler
- Properties of salt
- Variation of properties of bitumen modified with salt
- Change in behavior of bitumen modified with salt.

Emarah and Saleem (2017) investigated the use of lime treated soil mixed with seawater to determine engineering properties for roads construction. In clays, the introduction of swelling can result in stresses. Conclusions from the paper are summarized below:

- The use of seawater as mixing water for the lime-treated soil instead of potable water does not adversely affect the compaction process
- The higher bearing capacity of lime-treated soil was noticed in the case of using seawater as mixing water
- The presence of seawater as mixing water in the lime-treated soil has formed a new fabric structure of high rigidity as well as of high shear strength
- The plasticity index (PI) was reduced by 59% in the case of mixing the potable water with the lime-treated soil. Further reduction achieved was due to mixing the lime-treated soil with seawater, where the reduction reached 67%
- As the coefficient of compressibility (Cc) decreases, the compression potential decreases.

Otoko (2014) studied the effect of salt water on the physical properties, compaction characteristics and unconfined compressive strength of a clay, clayey-sand and base course material. Atlantic Ocean water was used to mix three soil types and its properties were compared with the results from the tap water study. Results showed that the plasticity index decreased from 13 using tap water to 5 using salty water for the clay, from 10 using tap water to 4 using salty water for the clayey-sand and from 6 using tap to 1 using salty water for the base course.

The effect of sea water from the Persian Gulf was investigated on the proctor compaction and California Bearing Ratio (CBR) tests on SP-SM (poorly graded sand with silt and gravel) soil samples, which were taken from five trial sections. The maximum dry unit weight increased by adding the Persian Gulf water when compared to the samples tested using tap water in the laboratory. A higher maximum dry density was noted for the Proctor test for the Persian Gulf Water samples. (Alainachi and Alobaidy, 2010).

Ismeik et al. (2013) investigated the stabilization of fine-grained soils with saline water. Material and chemical properties of the soils and water used were published including atterberg limits, soil classification, chemical analysis, compaction properties and unconfined strength with favorable results.

The Australian Road Research Board (ARRB) developed a road base test kit to determine the quality of water used for construction. The estimation of salinity (total dissolved salt content) is obtained from the electrical conductivity of a water sample to provide guidance on the sustainability for use in construction and possible environmental effects. The requirements typically limit dissolved salts to 10 000 parts per million (ppm) (Austroads, 2018). Research has identified that degradation from the introduction of salts in the road pavement is a two stage process (NSW Agriculture, 2003):

- Build-up of stresses within the aggregate particles
- Degradation of the aggregate particles

3 MATERIAL ACQUISITION AND SAMPLE PREPARATION

The subbase material used for pavement construction is depicted in Figure 2. G5 and G6 material (as per Colto specifications (2009)) was sampled from selective quarries in South Africa. The parent rock type and location of the quarry is given below:

- G5 Tillite (Ridgeview – Durban)
- G6 Sandstone (Qala – Durban)
- G6 Dolerite (Rooikraal – Johannesburg)

The material was washed, dried and sampled before testing could continue. Quarries positioned in KwaZulu Natal (KZN) were primarily sampled due to their end-use and proximity with the sea. Approximately 300 kg of material from each quarry was collected (Figure 2).

The seawater was obtained from Blythdale Beach in KZN. As per the South African Water Quality Guidelines (2012), the sampling process follows:

- Samples were collected where the depth of the water was less than 0.5 metres
- The water was collected from 15 – 30 cm below the surface
- Water was collected on the seaward side of a recently broken wave
- Backwash water was not collected
- No filter was used.

4 METHODOLOGY

A material testing program was developed to test the impact of seawater on material properties. Normal tap water (Pretoria) was used as a control (baseline) for the testing programme. The relevant test methods are depicted in Table 1.

Table 1: Material-testing programme

Description	Test	Test Method
Control tests	Grading of aggregate	SANS 3001 GR1
	Bulk density	TMH1 B9
	Atterberg Limits	SANS 3001 GR10
	Maximum Dry Density (MDD)	SANS 3001 GR30
	CBR	SANS 3001 GR40
	Electrical Conductivity	TMH1 A21T
	pH of water sample	-
Impact of seawater	Variations in MDD and CBR	SANS 3001 GR30 / GR40

Figure 2: Top: G6 Dolerite, Bottom Left: G6 Sandstone, Bottom Right: G5 Tillite (Sub-base gravel material)

5 RESULTS AND DISCUSSION

5.1 *Aggregate*

The Advanced Material Testing Laboratory (AMTL) completed aggregate testing on the samples. The materials were described as well grade coarse gravel. The Grading Modulus (GM) indicated that the materials are of relatively good quality and meets the Colto specifications (2009) for G5 and G6 gravel.

Other material properties are depicted in Table 2. A maximum Electrical Conductivity of 0.15 S/m (or 0.10 depending on drainage) at 25°C is usually specified for untreated road and other pavement base courses (Netterberg, 2014).

Table 2: Properties of subbase material

Parameter	Result		
	Tillite	Sandstone	Dolerite
Relative density	1.380	1.356	1.801
Relative density (compacted)	1.558	1.508	2.017
Electrical conductivity (S/m)	0.03	0.01	0.09

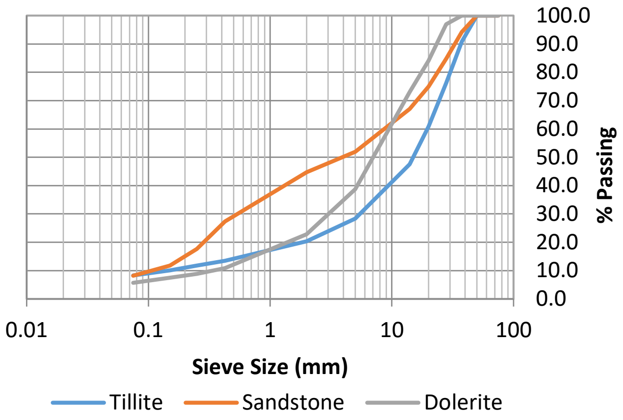

Figure 3: Aggregate material grading

5.2 *Water quality*

Netterberg (2014) specifies a pH between 6.0 and 8.5 for use on untreated materials. The tap water and seawater all met the specifications. Two sets of results are depicted in Table 3.

Table 3: pH of water samples

Water used on sample	pH of water samples	
	Tap water (control)	Seawater
Dolerite	8.2	8.1
Sandstone and Tillite	7.6	7.9
Netterberg (2014) target	6.0 – 8.5	

5.3 *Atterberg Limits*

Atterberg Limits are empirical tests which are used to indicate the plasticity of fine grained soil by the differentiation of highly plastic, moderately plastic and non-plastic soils. The material specifications for G5 and G6 material follows (Colto, 2009):

- *G5 material:* The Liquid Limit shall not exceed 30, Plasticity Index shall not exceed 10 and Linear Shrinkage shall not exceed 5%.
- *G6 material:* The Plasticity Index shall not exceed 12 or a value equal to 2 times the Grading Modulus plus 10, whichever is the higher value, and the Linear Shrinkage shall not exceed 5%.

Table 4: Atterberg limits of Tillite and Dolerite

Parameter	Tillite		Dolerite	
	Tap	Sea	Tap	Sea
Liquid Limit	15.94	16.13	19.51	19.21
Plastic Limit	12.85	13.23	17.43	17.31
Plasticity Index	3.08	2.90	2.08	1.90
Linear Shrinkage (%)	1.67	1.33	1.62	0.65

All samples met the Colto (2009) specification for material as stated above. The G6 Sandstone Material was described as non-plastic. It can be seen that the Liquid Limit and Plastic Limit depicted a small deviation whilst the greatest deviations can be seen in the Linear Shrinkage.

5.4 *Compaction*

Compaction testing was completed according to SANS 3001 Method GR30. Colto (2009) specifies that the maximum swell at 100% modified AASHTO shall not exceed 1.0% for G6 and 0.5% for G5.

- All samples met the maximum swell criteria
- A lower OMC is required for Sandstone and Dolerite
- A higher MDD is achieved for Tillite and Sandstone
- The deviation for the MDD achieved was at most 2% for all samples.

Table 5: Compaction results of tap (control) and seawater for subbase material

Parameter	Tillite		Sandstone		Dolerite	
	Tap	Sea	Tap	Sea	Tap	Sea
MDD (kg/m^3)	2232	2243	2108	2119	2421	2379
OMC (%)	2.7	6.3	6.8	6.6	4.2	3.3
Mould A: % of MDD	100	100	100	100	100	100
Dry Density	2215	2226	2169	2150	2500	2388
Moisture Content	6.3	6.7	7.0	6.4	3.7	2.6
% Swell	0.0	0.0	0.0	0.1	0.0	0.0
Mould B: % of MDD	98	99	96	96	95	95
Dry Density	2166	2194	2076	2067	2375	2269
% Swell	0.0	0.0	0.0	0.1	0.0	0.0
Mould C: % of MDD	92	93	92	92	93	93
Dry Density	2043	2069	1994	1978	2325	2221
% Swell	0.0	0.0	0.0	0.0	0.1	0.0

MDD: Maximum Dry Density, OMC: Optimum Moisture Content, SANS: South African National Standard, Colto: Committee of Land Transport Officials, AASHTO: American Association of State Highway and Transport Officials

5.5 *California Bearing Ratio (CBR)*

The California Bearing Ratio (CBR) test is a strength test that compares the bearing capacity of a material with that of a well-graded crushed stone. A high quality crushed stone material should have a CBR at 100%. It is primarily intended for, but not limited to, evaluating the strength of cohesive materials having maximum particle sizes less than 19 mm.

Table 6 depicts the CBR results. The Technical Recommendations for Highways (TRH) 14 (1985) specifies the criteria for G5 and G6 material.

- G5 Material: The material should have a CBR after soaking of not less than 45 percent at 95% Mod AASHTO density and a maximum swell of 0.5 percent at 100% Mod AASHTO density
- G6 Material: The minimum CBR at 93% Mod AASHTO density should be 25.

Dolerite was the only material, which met the target criteria for its specific material classification. All samples performed negatively (decrease in CBR) with the exception of G6 Sandstone at 100% Mod AASHTO.

Initial and repeat testing was completed on G5 tillite material due to the results from the CBR. Figure 4 shows a clear downward / flattening trend of CBR of the material after 95% Mod AASHTO.

Table 6: CBR test results

Parameter (CBR)	G5 Tillite		G6 Sandstone		G6 Dolerite	
	Tap	Sea	Tap	Sea	Tap	Sea
CBR @ 100 %	44	43	112	118	172	100
CBR @ 95 %	44	40	57	48	108	52
CBR @ 93 %	-	-	36	22	77	34
CBR @ 90 %	20	20	-	-	30	10
Target	Not Met		Not Met		Target Met	

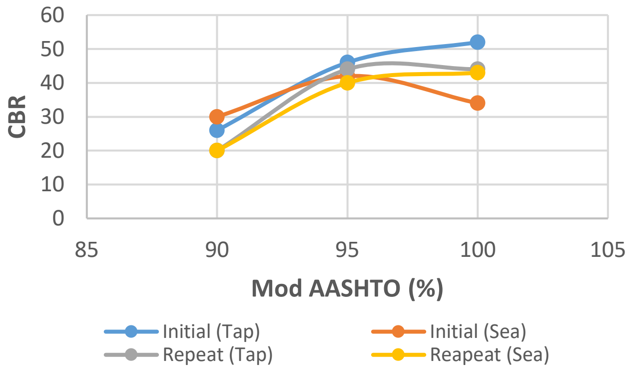

Figure 4: CBR of G5 Tillite material

Figure 5: Laboratory pictures: Density (top left), Atterberg testing (top right), Mixing of sample (bottom left), Compaction (bottom right)

6 CONCLUSION

There is great potential for using seawater as a non-potable source for pavement construction. Due to the state of available water in Southern Africa and the impact of climate change on road construction, there is a need for further investigation. Laboratory as well as in-field studies have been reviewed in this paper with quantifiable outputs.

This paper investigates the progress made in the field of non-potable water (seawater) use in road construction with the following conclusions and outputs:

- Subbase road building material (G5 and G6) was collected from quarries for laboratory testing (tillite, sandstone and dolerite rock types).
- Seawater was collected according to a sample process, with tap water used as a control for the testing.
- The materials were described as well-grade coarse gravel according to Colto (2009). The grading modulus criteria for all samples were met.
- The electrical conductivity and pH targets of the materials were met according to Netterberg (2014).
- All samples met the Colto (2009) specification for Atterberg limits with G6 sandstone being described as non-plastic.
- With relation to the compaction testing, all samples met the maximum swell criteria. A higher MDD was achieved for tillite and sandstone using seawater as opposed to tap water.
    - The deviation for the MDD achieved was at most 2% for all samples.
- G6 dolerite met the criteria for CBR testing using seawater.

7 RECOMMENDATIONS

The study showed promising results in the field of non-potable water in pavement construction. There is however, further research required with the following recommendations:

- Analysis of a wider range of aggregate materials as well as base layers in a laboratory setting using seawater.
- Chemical and variability analysis of different sources of seawater.
- Cost / economic variability of using seawater in inland areas due to transportation.
- Long-term pavement performance monitoring of constructed as well as trial (experimental) sections, which use non-potable water.
- Analysis of other non-potable water sources for pavement construction such as treated wastewater and grey water.
- Dry compaction of pavement sections.

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