PRESERVATION OF GRAVEL ROADS TO MAKE THEM DURABLE AND EROSION RESISTANT USING TECHNOLOGY DISRUPTOR NANO-SILANES

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ABSTRACT

The length of gravel roads in South Africa outnumbers the length of paved roads by a factor of three to four. Gravel roads have known lower vehicle/kms, but their mobility and access provision for communities are well recognised via initiatives like Sustainable Mobility for All (SUM4All) and overall Sustainable Development Goals (SDGs). The ever-decreasing gravel source issue coupled with diminishing maintenance and upgrade actions, place the maintenance and retention of gravel road networks under significant threat. The new draft TRH 24 (SANRAL, 2022) promotes the use of latest new-age modified emulsions (NME) using nano-technology (Nano-Silanes) as a low cost technology to upgrade to bituminous surfaced weather proof standards. This NME technology has real technology disruptor potential regarding the improved utilisation of lower quality natural granular materials in roads in general enabling lower cost in gravel road upgrade to paved bituminous surfaced standards. The case for application of this nano-technology for lower cost improved maintenance of gravel roads is made. NME is promoted here to be used as (special) gravel road maintenance, therefore not upgrade to paved standard. It has the potential for gravel preservation and makes sense with lesser funding and legislative hurdles as a gravel maintenance action in stead of upgrading such low traffic volume gravel roads to bituminous surfaced standard. If a gravel road status is retained the geometric and drainage design specifications do not have to be upgraded as for when it was to be upgraded to paved bituminous surfaced road standards. Thus, significant additional costs can be saved by retaining the road as a gravel road. Durable enhanced engineered low traffic volume gravel roads and streets can be provided by means of nano-technology. It retains the gravel road colour. This helps to manage public perception and expectations in terms of a darker colour that implies bituminous upgrading and higher standards. It makes the gravel surfacing and base water and erosion resistant with improved maintenance and operational functionality. Case studies are briefly referenced to demonstrate the potential.

Keywords: Gravel preservation, Water phobic, Anionic nano-silane modified bitumen emulsion, Erosion resistance.

1. INTRODUCTION

South Africa has the 10th largest road network in the world (Paige-Green, 1989 and 2010). The gravel road network length is four times that of the bituminous surfaced road network. In spite of known lower use, expressed as vehicle/kms, the mobility and access needs of gravel roads are well recognised and initiatives like Sustainable Mobility for All (SUM4All) and overall Sustainable Development Goals (SDGs) try to achieve these mobility and accessibility goals. In Figure 1 it is indicated almost 80% of the road network consists of gravel and dirt roads, yet the bulk of the yearly maintenance costs is assigned towards surfaced roads. The bar chart in Figure 1 indicates the relative proportional unit cost difference between surfaced and gravel roads.

Gravel roads are the most common road type found in rural areas providing basic mobility and access needs. Such gravel roads have a high demand for maintenance with re-gravelling and grading operations. Currently in SA ongoing significant gravel road maintenance back logs are recorded at provincial and local authority road departments. Gravel sources are known to be a scarce and a diminishing resource placing additional pressure on maintenance activities with significant negative environmental consequences. The focus of this paper is on improved gravel road maintenance actions. It demonstrates the enhancement of engineered gravel roads via gravel preservation treatment. It provides a cheaper option versus bituminous surfaced upgrading. In Figure 1 it is the option next to bituminous sealed low volume roads but now excludes the continuous re-gravelling and grading operations of normal gravel roads.

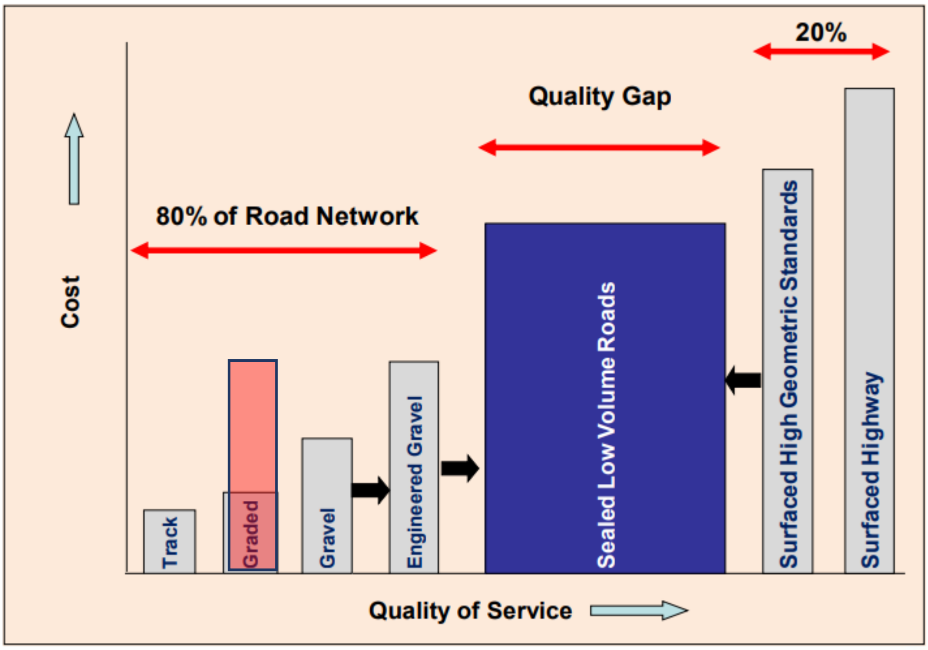

Figure 1: Conceptual cost and service quality benchmarking of road types (Paige-Green, 2010)

Gravel roads generally have lower traffic volumes than bituminous surfaced (paved) roads. Gravel roads are primarily providing accessibility and mobility needs to rural communities. They generally have lower geometric standards due to the road alignments which tend to “hug” the local topography, thus they also have lower operating speeds. Gravel road alignments results in limited fills or cuts, and limited major drainage structures (culverts, pipes and or bridges). In contrast, higher design speed and higher design standards (geometric, drainage and higher quality layer materials) are normally associated with bituminous surfaced roads. The lower traffic volumes on gravel roads (low to very low traffic volumes) tend to be exposed largely to environmental destructive effects as conceptually illustrated in Figure 2 (SATCC, 2003).

All roads, irrespective of traffic volumes, need a protective surfacing to help prevent moisture, environmental and traffic induced distress development. The design domain, or focus area of this paper, presented in Figure 2 is roads with a design life below 1 million equivalent standard axles (MESA) or an eight-year design life. The design domain concepts are highlighted in Figure 2. This design domain demarcation shows the main mechanism of distress development is dominated by the environment.

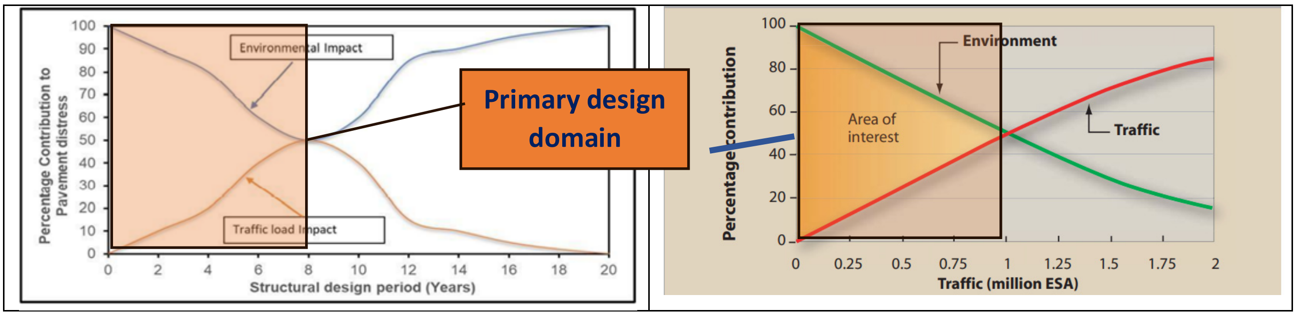

Figure 2: Illustration of pavement deterioration over time due to insufficient preventative protective road surface maintenance as per Draft TRH 24 (SANRAL, 2022 and SATCC, 2003)

Gravel roads suffer distress largely due to gravel loss. Gravel loss has different dimensions. It is known that some of the gravel loss occurs due to vehicle wheel abrasion, dust, wind and water erosion. The yearly estimated dust loss is 20.7 million tonnes (SANRAL, 2022) on the total gravel network. The maintenance actions of these gravel roads require large volumes of water. It is used for gravel resurfacing and compaction or as dust palliation. If the average gravel loss across the proclaimed gravel road network is 10 mm per annum, then 4.6 million m^3 of water, which roughly equates to 0.5 per cent of the capacity of the Vaal Dam, is required annually for re-gravelling (SANRAL, 2022). Water spray application for dust palliation on gravel roads is not included here, but creates a whole new dimension with regards to environmental impact.

From an environmental perspective it is clear other solutions should be found to effectively maintain the vast un-surfaced gravel network in SA. Gravel road maintenance is not inexpensive. Re-gravelling (150mm thick) can cost over R1.1 million per km for a 7m wide surface and ideally this activity may be required several times a year pending rainfall and traffic patterns. Erosion due to stormwater is probably the main reason for gravel loss on lower traffic volume gravel roads.

Experience with improvement/upgrading of low volume gravel roads by means of all-weather bituminous surfacing options are known to be expensive (SATCC, 2003) where expensive commercial source crushed stone products and a bituminous surfacing are used. The material quality of the existing gravel road base and surfacing layer is very seldom acceptable for direct use in upgrade designs as retained base material for bituminous surfaced standards. Such base and gravel surface layer material are often of a lower gravel quality and will typically have undesirable material characteristics like high Plasticity Index (PI) and or deficient grading, making it unsuitable to re-use as base layer materials for bituminous surfacing upgrades. Appropriate standards for low-cost upgrades of low volume roads were partially addressed in the past by various guidelines such as SATCC (2003), but had some short comings regarding improved in situ material utilization or retention as enhanced engineered gravel roads.

The Draft TRH 24 (SANRAL, 2022) launched in November 2022 goes a long way towards appropriate standards for cost effective paved upgrading as identified in Figure 1. It also makes the case to use in situ material cost effectively by means of innovative new-age nano-technology. The latter shows classical characteristics of a technology disruptor in the road pavement design and construction environment. Draft TRH 24 focuses on applicable standards and optimization of the use of existing in situ naturally available materials. The aim is to provide for the cost-effective upgrading of unpaved roads without compromising the safety of the road user as well as the integrity of the road pavement structure. The design guideline aims to maximize opportunities for Small Medium and Micro Enterprise (SMME) and labour enhanced work development. To this effect recommendations and guidelines are provided for:

1. Geometric design standards;
2. Drainage standards;
3. Pavement structural evaluation and design methods;
4. Material design for the optimisation of the use of naturally available materials using proven and available New-age (3rd millennium) or Nano Modified Emulsions (NME) technologies; and
5. Implementation of method of contract incorporating “End use/product specifications” to which the use of NME products must adhere to during design and construction in a “prove of concept” evaluation process.

2. DESIGN FOCUS OF ENHANCED GRAVEL ENGINEERED ROADS

The design recommendations contained in the Draft TRH 24 are typically aimed at the surfacing of roads carrying less than 300 vehicles/day or less than 3 MESA traffic loading. This covers the road categories D and E shown in Table 1 as described in Draft TRH24 (SANRAL, 2022). As mentioned before the current design domain aims at road category E with less than 1 MESA traffic. It is however realized that there are numerous unpaved gravel roads currently in operation in South Africa with considerably higher volumes of traffic. Such higher traffic volumes dictate that their design standards to upgrade towards paved standards are described elsewhere in a variety of documents inclusive of TRH 4 (1996).

Table 1: Number of vehicles and design traffic loadings to be considered for design purposes for the upgrading of gravel/soil roads

Road Category	Vehicles per day	Activity along Road - Local Communities together with	Assumed Design Traffic Loading (million E80s) or (MESA)*
D	200-300	Several farming/plantations/packhouses	3.0
		Some seasonal farming activities	1.0
E	100-200	Farming activities and local deliveries	1.0
		Tourism / local deliveries	0.5
	<100	Remote communities	0.1-0.3

*Million Equivalent Standard (80kN) Axles (MESA)

The Category D and E roads, defined in Table 1, are primarily linked to the number of vehicles and the number of trucks to be carried on these roads. It is clear the focus of draft TRH 24 is road class D with vehicles per day ranging between 200 and 300. This traffic class has always been the area where most intense analyses of the Benefit Cost Ratios (BCR) described in Draft TRH 24. The BCR analysis tends to wrestle to get an acceptable answer to justify upgrading and surfacing gravel roads to bituminous standards. Road departments have largely based their surfacing strategy on the HDM-4 derived guideline, without regard to marginal or dynamic efficiencies. The generally accepted requirement is that Average Annual Daily Traffic (AADT) must exceed 200 vehicles per day to justify upgrading such an unpaved/gravel road to a bituminous surfaced standard. In practice this standard has been largely not achievable due to budget constraints. The result is that many unpaved roads actually only qualify to be upgraded to a surfaced standard once AADT exceeds 500 or even 1 000 vehicles per day (vpd). Thus, the gravel roads in the traffic range of the class D and E roads (Table1) are by implication destined to stay gravel roads for a prolonged period due to this high hurdle imposed by HDM-4 type analysis.

In the case made here, the focus is not to provide a bituminous surfacing and upgrade the road in terms of structure, or geometrics and drainage, but to preserve the existing gravel, make it hydro or water phobic, erosion resistant, retaining the existing geometry and minor adjustments to existing drainage provision. Therefore, only aspects related to bullet points 4 and 5, presented or discussed in the previous section, need to be attended to while bullet points 1 (geometrics), 2 (drainage) and 3 (pavement structure) can be largely circumvented or stay as is.

3. FOCUS ON GRAVEL ROAD MAINTENANCE RATIONALE

3.1 Source of Funding

In order to maintain the road network, national treasury ringfence funds specifically for road maintenance through the Division of Revenue Act (DORA), which include the equitable share and conditional grants such as the Provincial Road Maintenance Grant (PRMG). This dedicated pool of funding is a yearly allocation and is released based on the results from Road Asset Management Systems (RAMS) submitted to treasury by all road departments as described in TRH 26 (SANRAL, 2012). This funding stream is exclusively for maintenance activities as defined by the DORA Act: routine maintenance, periodic maintenance, and special maintenance (operational expenditure - Opex). The use of PRMG funding for Rehabilitation (capital expenditure - Capex) is discouraged and may in any case not exceed 25% of the PRMG allocation.

Funding of Capex projects is more complex and is prescribed in the Framework for Infrastructure Delivery and Procurement Management (FIDPM) as an instruction in terms of the Public Finance Management Act (Act 1 of 1999). The FIDPM prescribe the stages of planning before funding will be released for Capex projects which includes among others, a 10-year Road Asset Management Plan, an approved Business Case, a 3-year Expected Capital Expenditure (ECE) list and an implementation plan. The releasing of funding to, for instance the upgrading of gravel roads to surface standards (Capex funding) requires, therefore, a different more complex and lengthy process which can significantly delay the upgrading of urgent gravel roads.

It is important to develop technologies to effectively preserve the gravel network through intelligent maintenance strategies. These maintenance activities can be funded through PRMG funding as described above much faster than the motivation of funding for paved standard upgrading (the FIDPM route). In additional to this, road maintenance is normally executed through multi-year (3-year) term contracts which ensures fast and effective deployment of urgent maintenance. It would, therefore, be logical to focus on maintenance work of gravel roads than to try to upgrade them. The funding hurdle is much lower.

3.2 Cost of Upgrading Versus Special Maintenance

The second challenge is to lower cost of such engineered gravel roads versus bituminous surfacing upgrade options. Gravel roads by nature have limited and relaxed geometric and access standards. The main function of rural access/activity roads is to provide access to individual properties such as farms, settlements, mines, tourist areas, game and nature parks, etc. as described in TRH 26 (SANRAL, 2012). As soon as you upgrade gravel roads to paved roads, minimum standards in terms of geometrics (sight distance, vertical and horizontal alignment), access/intersection spacings, and drainage requirements must be applied as now also described in draft TRH24 (SANRAL, 2022). These aspects have major cost impacts.

3.3 Cost of Materials

The last factor to consider is the nature of the material used for gravel roads as opposed to bituminous surfaced (blacktop) roads. The ideal material used in gravel roads should consist of a significant percentage of clay. Significant reductions in gravel loss can be obtained by selecting material with a suitably high plasticity index (PI). The downside of this requirement is when you upgrade to a bituminous surfaced road standard, all the material suitable for the gravel road must be removed because high percentages of clay have a serious detrimental effect on the durability of surfaced roads. To avoid this excessive spoil of unsuitable material it is important to seek alternative technologies to stabilise and preserve the existing granular material without having to remove it.

If significant alignment improvements are made to bituminous surfaced options, the potential utilisation of the in-situ material can diminish due to cut and fill requirements. There is therefore significant costs impact still for such cut and fill operations, even if lower quality material (e.g. G6 to G8) material are still sourced to be treated as NME treated base and or subbase. In the new TRH24 this is largely addressed by the promotion of new-age emulsions using nano-silanes of which a prime attribute is the encapsulation of clay minerals and making such lower quality material water proof and water resistant. The cost of the bituminous surfacing, after geometry and drainage issues addressed as discussed before, on itself isa significant cost item. This cost aspect therefore will not be added to NME treatment for gravel preservation. In the case of gravel preservation via NME treatment the in situ gravel can be treated in situ with the minimum of material needed for make up. Admittedly the NME treatment still adds to the cost, but without the cost elements of bituminous surfacing and geometric upgrade described above, with clear gravel preservation benefits, as described above.

4. PERFORMANCE AND DURABILITY FOCUS OF NME END USE SPECIFICATIONS

4.1 Mineral Identification and Match at Nano Level

Considerable development work with Bitumen Stabilised Materials (BSM) (Asphalt Academy, 2009) guidelines and specifications have taken the knowledge pool forward versus the old standard cement and lime stabilisation options for gravel stabilisation. The design and evaluation specifications of BSM have shown the value of Unconfined Compression Strength (UCS) tests as well as Indirect Tensile Strength (ITS) testing correlated with triaxial testing done in the dry and wet state. Considerable development work had also been done with Nano technology (Jordaan & Steyn, 2021, 2022) since after the first BSM guidelines appeared.

A fundamental difference between this Nano-technology research and development work versus other unconventional soil stabiliser products has been the emphasis placed on the fundamental aspect of mineral identification in the gravel to be treated. The nano-silanes in the NME form a permanent chemical bond with the Si in the gravel/soil. The X-ray diffraction (XRD) results also relate to the identification of deleterious secondary minerals (such as Muscovite, Chlorites and Montmorillonite, etc.) and qualification with sophisticated tests like XRD analysis for mineral identification and quantification (Jordaan & Steyn, 2019, 2020, 2021, 2022).

The nano-scale of the nano-silane brings to bear the fundamental impact of specific area with relation to the clay particles size (also nano-sized) ensuring proper linkage and cover, thus providing the desired water phobic characteristic. This water phobic characteristic is seen as a major positive feature. It also means reduced bitumen emulsion concentrations are needed compared to normal Bitumen Stabilised Material (BSM) treatments. The NME bitumen emulsion requires modification to ensure smaller bitumen droplets are linked with silicon (Si) in the gravel as a strong chemical bond, not merely relying on adhesion. The chemical bond allows the use of the New-age (Nano) Modified Emulsion (NME), without any cement needed in the mix, with major advantages related to comparable strength development, sustained elasticity and flexibility of the treated granular material.

4.2 Durability

This development work on NME led to specifications that are in agreement with the BSM specifications and building on it. In Table 2 it is illustrated via the comparison criteria how NME treatment can use lower quality untreated granular materials (UGMs) (typically G 8 to G 6). The traditional cemented materials tend to typically use G 6 or G 5 or G4 as better-quality materials. The BSM treatment also prefers material of a G 6 quality and better.

The Retained Compressive Strength (RCS) is the ratio of UCS_{wet}/ UCS_{dry} as well as the Retained Tensile Strength (RTS) specified as the ratio of ITS_{wet}/ ITS_{dry}. Currently only BSM includes a wet ITS and triaxial tests, while for cemented materials wet/dry ratio is not part of the specification. Recent work on gravel road upgrade and pothole patching (Jordaan & Steyn, 2021) provided credibility to the use of RTS and RCS as durability performance indicators. It is, therefore, logical that these specifications can be applied to NME stabilised gravel roads as well. These specifications have already proven themselves in practice and enable the provision of durable, flexible and water-resistant road bases and pothole patching material using NME technology (Jordaan & Steyn, 2019, 2020, 2021, 2022).

Table 2: Summary comparative table of NME versus cement stablisation as well as Bitumen Stabilised Material (based on Draft TRH24)

Material Class	G3 to G1	G4 and better	G5 and better	G6 and better
Cemented Mat Class	C1	C2	C3	C4
UCS (MPa)	- >6	6 - >4	4->3	1.5 -0.75
ITS (kPa)			>250	200->160
ITS (wet) (kPa)	>240	240 >200	200 ->160	160 -> 120
Retained Compressive Strength (RCS) (UCS(wet)/UCS (dry) (%)	>85	>75	>70	>65
Retained Tensile Strength (RTS) (ITSS(wet)/ITS (dry) (%)	>85	>75	>70	>65
NME Class	NME1	NME 2	NME3	NME4
Material Class	G1 - G2 - G3 - G4 - G5 - G6	G7 and better	G7/G8 and better	G8/G9 and better

4.3 Strength Requirements

Gravel roads tend to be moulded into a balanced pavement strength in depth over time. In Figure 3 the stress distribution of a tyre is illustrated (SATCC, 2003). It clearly shows how the stress distribution is reduced from a contact stress varying between 600kPa and 900kPa to less than half of that depending on the quality of the base and surfacing layer material. If the base and surfacing layer is of a higher quality and has significant strength this reduction is very significant on the lower layers of the pavement structure. This strength can be measured in situ with the Dynamic Cone Penetrometer (DCP) penetration rate parameter (DN mm/blow). It generally provides strength evaluation even to a depth of 800mm of the total pavement structure. A pavement can thus be evaluated based on the contribution to total strength based on the ratio or percentage of the DN of the top 100mm or 150mm to the DN of the total 800mm depth.

The use of the DCP has also been found to give a clear indication of the initial curing period (typically 48 hours) during which the NME treated base material may still be "soft and sensitive". It invariably allows monitoring achievement of a lower penetration rate after curing at the desired rates and ranges.

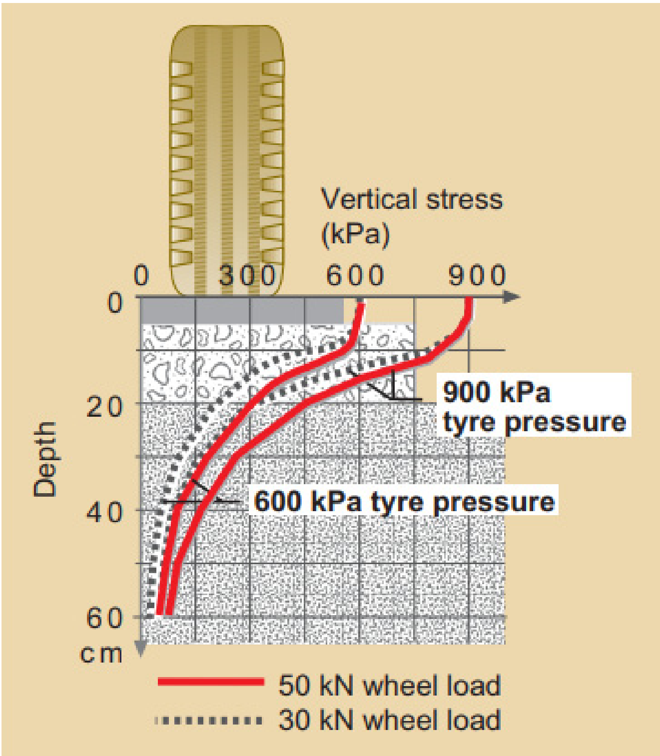

Figure 3: Stress distribution in pavement depth (SATCC, 2003)

Determining the DN value fora NME4 treatment an average of 3.5mm/blow would be required. This is merely another way of showing the benefit of the top 150mm can be monitored in the field and is bound to show significant strength improvement of the pavement structure as well due to the improved stress distribution/protection to the lower layers. In some instances it may also be beneficial to merely treat the top 75mm to 100mm with NME to achieve such stress distribution benefits.

5. PROOF OF CONCEPT EXAMPLES

5.1 Introduction

This concept of engineered gravel providing gravel preservation, water resistance, erosion resistance and durability in strength and resistance to wheel action does not have any real or long track record yet. Engineered gravel implies special maintenance re-gravelling and NME type stabilisation. It is clear this is a niche application of NME treatment which should be classified as enhanced engineered gravel maintenance. There are however a few distinct examples where the concept had been successfully applied or demonstrated.

5.2 Documented Case of a G8 Base Stablised With NME

The D1884 rehabilitation project near Heidelberg, Gauteng Province, was constructed using a nano-silane New-age Modified Emulsion (NME) (Jordaan et al, 2017, Rust et al, 2019*).* Existing G8 material was used as base and subbase layer when it was stabilised with NME. The design life of this pavement structure was to reach at least 3 MESA. This is as indicated before (Fig 2) the target design domain.

In NME stabilised G8 base material results on D1884 was designed in accordance with the XRD results inclusive of a significant concentrations of Micca found in the soil.

A section of the D1884 was tested with the Heavy Vehicle Simulator (HVS) with very good performance results and was reported in detail during CAPSA 2019 (Rust et al, 2019). Only relevant information is mentioned here. What makes this an ideal reference for the concept of enhanced engineered gravel road maintenance is that the bitumen surfacing came off early during the HVS testing (oil spill) and the test was continued on top of the exposed base layer with no surface crushing or ravelling effects.

During the HVS test 3.5 million equivalent axle loads (MESA) were applied which resulted in only an 8 mm rut depth. For gravel roads 20mm rut is the trigger value for rehabilitation. This indicates that the NME treated base and subbase may be able to carry the design traffic of 3 million equivalent axles and possibly much more.

5.3 R504-3 Clearseal Treated G7 Temporary Bypass

Two cuts on the R504-3 (Wolmaransstad to Leeudoringstad) SANRAL project provided a short-term opportunity to test the use of clear or transparent Nano-Polymer Nano Silane (NPNS) as stabilisation. The main purpose was to ensure no colour change would occur in the G7 material surface as well as adding strength. The reason for this treatment was to provide a temporary bypass through the cut area to facilitate rock blasting on both sides taking place in phases. No layer works could be done due to fears of fruitless work and damaged layers due to the future blasting next to it. The one cut section at km 7 (1200m length with width of 3.5m) was treated with 1.1% NPNS. The material design test results are shown in Table 3. No XRD analysis was done due to the urgency associated. Only normal Atterberg Indicators and grading test results were available confirming it as a classical G7 quality material. The treated material indicated that it qualified for a NME4 minimum treatment and probably result at best a NME3 material equivalent. The top 50mm of the placed roadbed prepared G7 material was scarified with a grader, sprayed with the NPNS (also known as Clearseal) solution and compacted in the Cut at km 7.

Another 600m, also 3.5m wide, was similarly treated with Clearseal through the cut at km 10. In this case the Clearseal was mixed in with an in-situ recycler to a depth of 100mm and compacted. This temporary surfacing lasted through the holiday break and at least another month of direct channelized traffic. The roadbed had to be reworked to facilitate an emergency repaired bypass. The Clearseal treated bypass through cut at km 10 picked up limited defects due to the blasting damage, but could still be maintained with pothole repairs with the same Clearseal and G7 material with hand labour.

Both cut sections temporary bypasses with Clearseal treatment were exposed to an estimated 1 000 vehicles per day with 15% heavy vehicles for a period of 21 days. In Figure 5(a) the Clearseal mixing in preparations are shown and in Figure 5(b) the final surface condition after trafficking over the holiday break is shown.

Table 3: RTS and RCS values for G7 quality material use don temporary cut bypasses

Treatment application rate	**ITS dry (kPa)**	**ITS wet (kPa)**	**UCS dry (MPa)**	**UCS wet (MPa)**	**RTS= ITS_{wet}/ ITS_{dry}**	**RCS= UCS_{wet}/ UCS_{dry}**
1% Geo-Nano +1.5	270	170	4.11	3.10	75%	**63%**
12 l/m^3 NPNS or Clearseal	335	260	5.09	2.9	78%	**57%**
NME classification					NME3	NME4 to NME3

Figure 4: NPNS I treated temporary bypass as enhanced engineered gravel

This was only a short-term experiment which was geared more towards proof that the Clearseal can provide an enhanced engineered gravel surface as a bypass. It also proved the Clearseal definitely does not change the surface colour and withstood significant traffic for an initial short period (at least 21 days) without any rut development or pothole development. Subsequently due to subsoil installation this exposure to channelised traffic extended to three months with good performance and limited maintenance needed.

5.4 Commumunity Development Project in the Maquassi Hills Municipality

SANRAL provided approximately R 30 million for the Community Development Project (CDP) in Maquassi Hills Municipality (Wolmaransstad, Witpoort and Leeudoringstad). The streets in these rural town had deteriorated very badly due tot lack of maintenance. A number of streets were identified to be treated with NME. Tau Pele acted as main contractor and local companies meeting the required CIDB grading were appointed after work packages were tendered for. The type of street treatment varied from basic gravel preservation of very low traffic volume basic access streets (less than 5 vehicles per day (vpd) in Witpoort) to classic access streets where traffic volumes are less than 75vpd found typically in Wolmaransstad and Leeudoringstad and a major collector street in Leeudoringstad. The NME treatments for surfaced streets are reported by Horak et al (2024), but the gravel preservation treatments have specific relevance here.

The gravel preservation of the Witpoort streets involved preparation with a grader, compaction and spray with NPNS or Clearseal. This is a very basic and ultra low volume gravel preservation treatment and in line with findings by Range and Horak (2007) that Nano- technology treatments have significant benefit with regards to erosion protection. In a few streets the preparation was done as described above for the full depth of 150mm of in situ gravel and then 75mm of the top was treated with 1.2% NME afterwards. It was also sprayed with NPNS or Clearseal after compaction. One of the gravel preserve treated streets (Rissik on Makwassie side of R504) acted as access to the construction goods yard and inevitably carried a significant number of heavy trucks. This street performed very well for a period of 4 months before the contract ended and traffic dipped down to that of a basic access street.

Paige-Green (2005) and Range and Horak (2007) had previously shown that gravel streets show significant resistance to water erosion if the density of the base and surfacing layer are compacted to higher densities than normally specified. A variation on this theme was done on the very low traffic volume streets on the Klerksdorp side of the R504. After compaction some of these streets only received a NPNS or Clearseal sprayed on surfacing. The immediate result was a water phobic surface. However after 4months of seasonal rain it became clear the Clearseal did peal in some places even though the surface profile was still in a very good shape.

At least two other basic access streets also received such in situ recycling (previously a bituminous surfaced street) with NME and Clearseal surfacing. Part of the reason was to “spread the sunshine” to such very low traffic volume streets for all in the local municipality. This approach also allows for a workable phased construction. The municipality typically can allocate budget for the bituminous surfacing (eg Cape seal) in future. In the interim the road is gravel preserved. These streets were completed end of mid December 2023. At the end of January 2024 significant seasonal rains had fallen and these streets performed very well. It is admittedly still early in the life of the street and therefore they will be monitored periodically in future to observe their performance under normal town traffic.

6. COST BENCHMARKING

The draft TRH 24 (SANRAL, 2022) clearly alert to the fact that the normal HDM4 type analysis will not favour upgrades at low traffic volume figures for various reasons. A different approach is needed to look at the case for enhanced engineered gravel road maintenance described in this paper. A very simplistic first level benchmark comparison would be to compare the cost of say 150mm in situ NME treatment and or with Clearseal finishing, with the cost of conventional re-gravel and regrade of a gravel road. As previously mentioned, in the introduction, this latter cost is typically R1.1 million/km per year if done only once a year for a 7 m wide gravel road. The tendered rates for the Maquassi Hills CDP described above with a comparative 150mm deep NME special maintenance enhanced engineered gravel road base with a Clearseal surfacing has an indicative cost of approximately R 1.17 million/km. This is estimated to last at least 5 years with no or limited maintenance.

No road can be defined as maintenance free, particularly not low volume roads. The main reason is the impact of the environment. The NME treated road may therefore need routine maintenance. It is estimated a yearly maintenance of a Clearseal spray after sweeping it clean may be applied via watercart to retain the surface erosion resistance and wheel abrasion resistant. Such cost is estimated to be in the order of R0.3million/km per year. This implies if the NME enhanced engineered gravel road can be extended for ten years at R1.2 million plus 10x R 0.3 million = R4,2 million per km over ten years. The equivalent normal gravel maintenance and repairs will cost R1.1 million X 10 = R11 million over the 10 years. If re-graveling and regrading were to be done twice a year this comparative saving estimated will be even more than R14 million/km. This implies approximately R7 million minimum (and up to R10 million/km) can be saved over ten years on such an NME enhanced maintenance treatment with Clearseal surfacing. No current longer-term projects are available to evaluate this potential saving further, but clearly the potential saving shown here on a very basic level is significant.

6. CONCLUSION

The fact that gravel road length in SA is approximately four times the length of paved roads is only one indication of the pressing need to upgrade gravel roads for mobility and accessibility needs. The new draft TRH 24 (SANRAL, 2022) is addressing the need for more realistic and fit for purpose specifications for the upgrade of gravel roads to bituminous surfaced standards in South Africa. The significant cost reduction made possible by the proven use of NME treatment of lower quality gravel material (in situ in most cases) is a clear motivation to use NME in the possible upgrading of gravel roads to bituminous surfaced paved standards. The traffic range for such upgrades of typically 1 to 3 MESA is known to largely cater for the destructive effects of the environment and to a much lesser extent for the destructive effect of traffic.

This same range of low traffic volume gravel roads (up to 3 MESA) can however now also be maintained with NME treatment as an enhanced gravel engineered option. No geometric and drainage upgrades are required. The legislative and funding restrictions on maintenance actions (Opex funding) are much less arduous than if the road is to be upgraded to paved road standard, even as per the Draft TRH 24 standards (Capex funding). This NME treatment allows the gravel road to have the same gravel colour as prior to treatment, be water repellent (water phobic), show increased strength and durability via ITS and UCS wet/dry ratios as specified in TRH24, but without a bituminous surfacing. The NME treated materials also do not show any cracking or crushing sensitivity as normally found with cement stabilised materials as it becomes a durable flexible material.

This concept had already been proven to perform very well by default via HVS testing (Rust *et al*, 2019). It showed a G8 base with NME treatment can carry more than 3 MESA with direct exposure to the loaded wheel without an asphalt surfacing. Other anecdotal short experiments on NME treated roads and bypasses have shown it can perform as required similar to a bitumen surfaced road.

On a basic cost benchmark basis, the cost per km for the NME stabilised enhancement as an engineered gravel road is more than half of the annual average cost of re-gravelling and re-grading a typical gravel road. More longer-term projects are currently planned which will help to populate the technical performance and cost benchmarking in future.

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