

THE ECONOMIC BENEFITS OF HVS DEVELOPMENT WORK ON G1 BASE PAVEMENTS

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EXECUTIVE SUMMARY

This report describes the assessment of the economic benefits stemming from HVS investigations that resulted in the development of a technology for the design and construction of pavements with high quality Crushed Stone base layers. This high quality Crushed Stone, known as G1 material in South Africa, provided a viable alternative to the thicker and more expensive pavements that were typically considered for heavily trafficked roads at the time when the HVS investigation findings were published (roughly 1980 to 1982).

Historical Background

The background to the development of G1 technology is described and the key findings of the investigations (already presented in numerous reports and international publications) are summarized and discussed. Key elements of this discussion include:

- The development of the technology for the design and construction of G1 base pavements was an extended process which was partly initiated by the former Transvaal Roads Department (TRD).
- Before the HVS investigations on G1 base pavements were conducted (between 1978 and 1982), there was considerable controversy over the structural capacity boundaries within which G1 base pavements could be expected to perform well. At the time there was doubt whether G1 base pavements could be used for the higher traffic loading applications (specifically, but not exclusively, the 12 to 50 MISA traffic category).
- The development of HVS technology was classified into two phases. These were: (i) a basic technology development phases from the early 1960's to roughly 1978, and (ii) a validation and refinement phase (1978 to 1985), in which the HVS played a pivotal role.
- There were several contributors to the successful implementation of G1 technology. The HVS development programme was one of these contributors, and played a pivotal role in validating the earlier analytical work of Maree (1978) and others. It also provided an organized structure to the documentation and validation of the performance of G1 base pavements.

Technical Impacts and Benefits

The key impacts of HVS investigations on G1 base pavements were identified as:

- The suitability for G1 base pavements for the 12 to 50 MISA design class was clearly proven;
- The feasibility of G1 base pavements in wet regions was proven (provided an impervious surfacing could be maintained);
- It was found that the damage exponent (or n-value) of pavements with a G1 base over a thick cemented subbase was close to 3, and not 4.2, as was commonly assumed;
- It was proven that a 150 mm thick G1 layer is optimal for G1 base layers;

- The difference between the high quality G1, and lower quality G2 material was clearly shown;

Since the HVS investigations was only one of the contributors to the successful implementation of G1 technology, any evaluation of economic benefits should take into account the relative contribution of other role players. Therefore, for each of the identified impacts a relative contribution percentage was assigned and validated through interviews with acknowledged industry experts. It was noted that the HVS investigations also had other impacts, such as those relating to Science and Technology development, but that these cannot be readily evaluated in economic terms.

Economic Benefits

After consideration of the identified impacts, and specifically of the data and assumptions needed to convert the impacts to economic benefits, it was decided to combine the identified impacts into the following three main benefits:

Benefit 1: Increased use of G1 Base Pavements for higher design classes and wet regions

Benefit 2: Use of 150 mm maximum thickness for G1 base layers

Benefit 3: Improved maintenance and construction practices

The savings derived from these three benefits were assessed in detail. In essence, this assessment used a probabilistic approach to aggregate the likely unit savings that typically resulted from the above three benefits. The overall savings were then calculated for the Gautrans and SANRAL networks, by using the unit cost savings, which was scaled to an absolute savings value using the total lane-km of G1 base pavements constructed by Gautrans and SANRAL in the period between 1980 and 1990. The assessment of economic benefits showed the following:

- The overall benefit cost ratio (i.e. for Gautrans and SANRAL) varies from 2.4 to 6.1, depending on the contribution ratio and discount rate selected. For a nominal discount rate of 8 per cent, the overall benefit cost ratio varies between 2.9 and 5.1, depending on the contribution ratio selected. This range of estimated benefit cost ratios is similar to the range of 3.8 to 4.9 reported for accelerated pavement testing performed in Australia (ARRB, 1992).
- For Gautrans, the estimated direct benefit derived between 1980 and 1990 from the HVS investigations on G1 base pavements is roughly between R2.2 and R14.8 million (in 2004 Rand terms). Taking into account the contribution made by Gautrans to the funding of HVS investigations on G1 pavements, this results in a benefit cost ratio of between 1.4 and 3.6, depending on the discount rate and contribution ratio selected.
- For SANRAL, the estimated direct benefit is roughly between R3.4 and R25.2 million (in 2004 Rand terms). This results in a benefit cost ratio of between 4.2 and 10.2. This benefit cost ratio is higher than that realized by Gautrans, mainly because of the greater scaling of benefits provided by the larger SANRAL pavement network.

It should be noted that the lower bound of these benefit cost ratios represent a total which consists of the sum of all the lowest estimated contribution ratio's. Thus the lower limit of the above noted benefit cost ratios represent a highly conservative estimate. It is also important to note that the benefits that were evaluated include only those aspects which could be converted to economic savings with reasonable confidence and assumptions. There are several other benefits resulting from the HVS investigations on G1 base pavements which cannot easily be converted to economic savings, yet are sure to impact positively on the Gautrans and SANRAL budgets and networks over the long term. These benefits include aspects such as:

- Calibration of the South African mechanistic-empirical design methodology;
- Technology transfer to local and international practitioners which raised the technical competence of designers working for Gautrans and SANRAL;
- Improved understanding of the systems behaviour of granular base pavements, and particularly the interaction between the granular base and cemented subbase.
- Improved understanding of the behaviour of cemented subbase layers under loading. This led to further research into the behaviour and performance of cementitious pavement layers.

Since none of the above impacts are included in the assessment of economic benefits, it will be appreciated that the above noted benefit cost ratios represent a lower bound estimate of the benefits of HVS investigations on G1 base pavements. As suggested by Scott et al (2002), the simple linear benefit assessment process that was followed in this study fails to take into account the further downstream benefits and the impact of these benefits on the population at large. This means that the benefit assessment documented in this report probably greatly underestimates the true benefit stemming from the HVS investigations on G1 base pavements.

GLOSSARY OF TERMS

Asphalt surfacing	Pavement surfacing made up of Hot-mix Asphalt
Base layer	The pavement layer underneath the surfacing.
Benefit cost ratio	A ratio to relate the cost and benefits of a project.
Cemented layer	Layer in which untreated granular material is treated with cement.
Crushed stone	High quality granular materials used for pavement layers, made up of crushed rock (sometimes including overburden) with a particle size distribution ranging from 37 mm to dust.
Contribution ratio	The percentage contribution a specific investigation to an impact.
Discount rate	The interest rate used to determine the present value of future cash.
Foamed bitumen	A method of treating granular materials with bitumen.
G1 – G10	Material classification for untreated granular materials. G1 is the best quality material.
Hot-mix asphalt	Asphalt prepared with hot mix asphalt and graded crushed stone
Internal rate of return	The discount at which the present value of future cash flows equals the cost of the project.
Life cycle cost	The total cost over the life of the pavement, discounted to a reference year.
Macadam	Crushed stone layer consisting of a uniformly graded aggregate.
Mechanistic-empirical	A pavement design method that analyses the pavement as a mechanism, and translates that analysis to expected bearing capacity using empirical relationships.
Plasticity Index	Indicator that measures the range of moisture content within which the material acts like a plastic solid. Clay materials generally exhibit a higher plasticity index while sandy materials exhibit a low or zero plasticity index.
Present worth of cost	The value today of a future cost, discounted to the present date
Subbase	Pavement layer underlying the base layer.

LIST OF SYMBOLS AND ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
CSIR	Council for Scientific and Industrial Research
E1 – E4	Traffic classes as used in pre 1996 TRH4 documents. E1 is the lowest traffic class and E4 is the highest traffic class
E80	Equivalent 80 kN standard axle load
G1 – G10	Material classification for untreated granular materials. G1 is the highest quality material.
Gautrans	Gauteng Department of Public Transport, Roads and Works
HVS	Heavy Vehicle Simulator
kN	kiloNewton
kPa	kiloPascal
MESA	Millions of Equivalent Standard Axles
MISA	Millions of Standard Axles
Mod. AASHTO	Modified AASHTO Compaction
NDOT	National Department of Transport
SANRAL	South African National Roads Agency Limited
Standard Axle	A standard measure of traffic loading, typically an 80 kN single axle
TMH	Technical Methods for Highways
TPA	Transvaal Provincial Administration
TRD	Transvaal Roads Department
TRH	Technical Recommendations for Highways

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1 INTRODUCTION

1.1 BACKGROUND

The South African developed Heavy Vehicle Simulator, or HVS, is a test unit capable of evaluating the rate and manner in which roads deteriorate within a short period of time. Whilst road deterioration would normally take place over a period of eight to twenty years, HVS testing can evaluate such deterioration within a period of three to six months.

Since 1978, the Gauteng Department of Public Transport, Roads and Works (Gautrans)* has owned a HVS machine, and contributed to the funding of the HVS Technology Development Programme, which is centred on the various Heavy Vehicle Simulators that have been operating since that time. From the early 1990's, the Gautrans HVS has been the only operational HVS in South Africa.

The HVS Technology Development programme is aimed at developing innovative and cost-effective solutions to identified problem areas related to road design and construction. Although the HVS technology development programme (hereafter also referred to as the *HVS programme*) is to a large extent focussed around the HVS machine, a significant portion of the work is focussed on data analysis and transmission of findings to the industry. The transmission of findings is typically effected through conference papers, presentations, seminars and workshops as well as through manuals and guidelines to aid designers in the implementation of technologies that were tested and improved through HVS projects.

The combined efforts and results of the HVS technology development programme has played a pivotal role in furthering road design and construction technology for Gautrans and South Africa in general. There can be no doubt that every road design undertaken in South Africa, at present and in future, will be influenced by results that were generated by the HVS programme over the past three decades. By contributing to the establishment of a cost effective road infrastructure, the implementation of HVS related findings and products undoubtedly has a positive, if sometimes indirect, impact on the people of South Africa. Furthermore, HVS technology exported overseas has led to international recognition of the excellence of South African road design and construction technology.

As can be expected, the cost of owning and operating the HVS machine and sustaining the analysis and transmission of findings is not insignificant. In the face of increased pressure on the roads budget, it has become essential to proactively define and quantify the benefits of the Gautrans HVS programme. Gautrans thus identified a need to develop and execute an appropriate methodology for quantifying the benefits of the HVS programme. *To this end, Gautrans, in October 2003, initiated an independent investigation into the benefits (economic and other) arising from the HVS technology development work.*

* The Gauteng Department of Public Transport, Roads and Works is generally referred to as Gautrans. Prior to 1994, this department was known as the Transvaal Roads Department (TRD). In this document, the term Gautrans will be used wherever possible. Owing to the historical context of this study, the term TRD will also be frequently used where required by the context.

1.2 FRAMEWORK FOR QUANTIFYING BENEFITS

As part of the study to evaluate benefits arising from HVS development work, an inception report was completed in January, 2004 (Jooste et al., 2004). In this report, a framework was presented for evaluating the benefits from HVS technology development projects. The framework recommended that the evaluation should be performed in two stages, as shown in Figure 1.

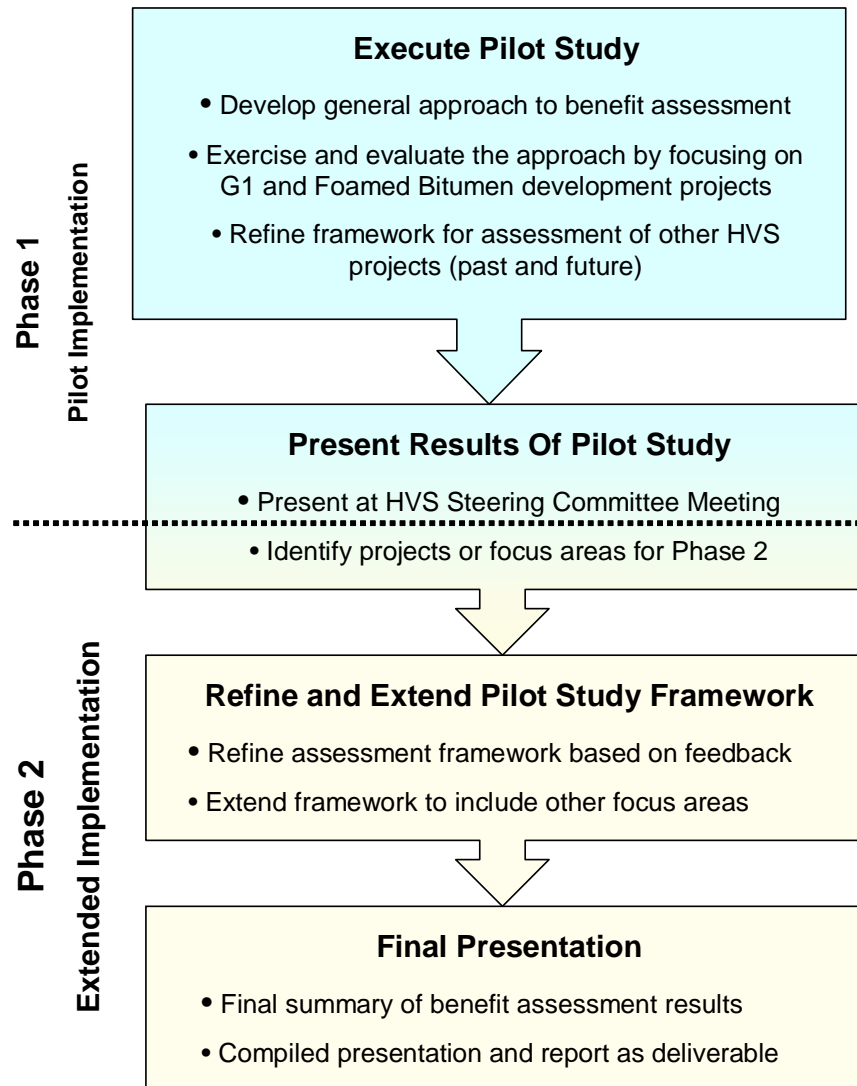


Figure 1: Proposed framework for evaluating the benefits arising from HVS Technology Development.

This report forms part of Phase 1 of the implementation framework shown in Figure 1. Specifically, the report summarizes the evaluation of the benefits arising from development work on high quality graded Crushed Stone materials known as "G1" material. This development work was performed mainly during the late 1970's to early 1980's, and thus represents a mature technology that has been implemented in Southern Africa for more than a decade.

1.3 OBJECTIVES AND SCOPE OF THIS STUDY

The objectives of this pilot study focusing on G1 materials, and of this report, are as follows:

- To identify and summarize the impacts made by the HVS investigations and development work on G1 materials.
- To analyze, quantify and document the economic benefits arising from the G1 development efforts.
- To exercise and refine the framework for benefit presentation presented in the earlier inception report.

As determined in the inception study, the scope of the investigations will not be limited to Gautrans alone, but will include those benefits that impacted on roads agencies and the broader population across South Africa. The study will not, however, consider impacts outside South Africa.

1.4 STRUCTURE OF REPORT

This report is structured in several chapters. Chapter 1 contains an introduction. In Chapter 2, the pavement design trends prior to HVS testing on G1 materials are discussed and Chapter 3 discusses the HVS investigations on G1 base pavements. Chapters 4 and 5 present the impact and cost of the HVS investigations, respectively. In Chapter 6 the economic benefits of the G1 development work are assessed. Chapter 7 contains the summary and conclusions and Chapter 8 the references. Five appendices are included and contain background information, calculations and the interview summaries.

2 PAVEMENT DESIGN TRENDS PRIOR TO HVS TESTING ON G1 MATERIALS

2.1 HISTORICAL DEVELOPMENTS

In South Africa significant use has always been made of unbound granular materials for pavement base course layers. Since the 1950s, changes in traffic loading intensity has led to a steady evolution in granular material design technology and in the use of unbound granular material for pavement base courses by the former Transvaal Roads Department (TRD). An overview of this evolution is summarised in Figure 2, and may be found in Maree (1982) and Kleyn and De Beer (2004).

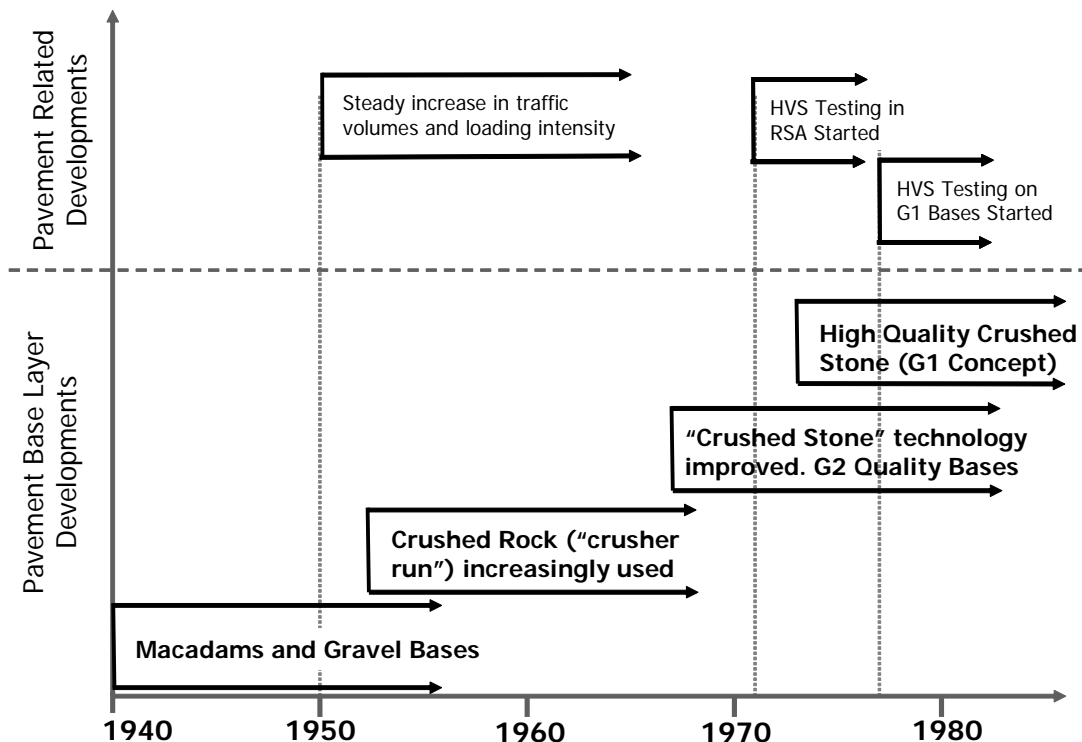


Figure 2: The evolution of unbound granular base pavements in South Africa

Until the 1950s, unbound granular bases in South Africa consisted mainly of natural gravel and various forms of Macadam (for more heavily trafficked pavements). The use of Macadam was discontinued mainly because of the slow construction process and consequent cost implications, especially for tar/bitumen bound Macadam. At the same time, traffic volumes were increasing and sources of base course quality gravel material were being depleted rapidly, especially within urban areas. In the United States and Europe, the increased traffic demand was mainly met through use of thicker asphalt base layers and concrete roads – both being significantly more expensive in South Africa than the Crushed Stone alternatives.

Because of this development, engineers increasingly started making use of cemented natural gravel and plant manufactured crushed rock (internationally referred to a "crusher run") bases for heavier pavements. Crusher run may loosely be defined as an unspecified composite of crushed rock (sometimes including overburden) having a

particle size distribution ranging from 37 mm to dust. This material was usually compacted in the same manner as natural gravel.

An extensive survey (Burrow, 1975) of the existing roads in the former Transvaal in order to assess the soundness of the TRD pavement philosophy and construction quality showed that while this type of base course was by no means prevailing, a significant percentage of the pavements had “crusher run type” base courses, as shown in Figure 3.

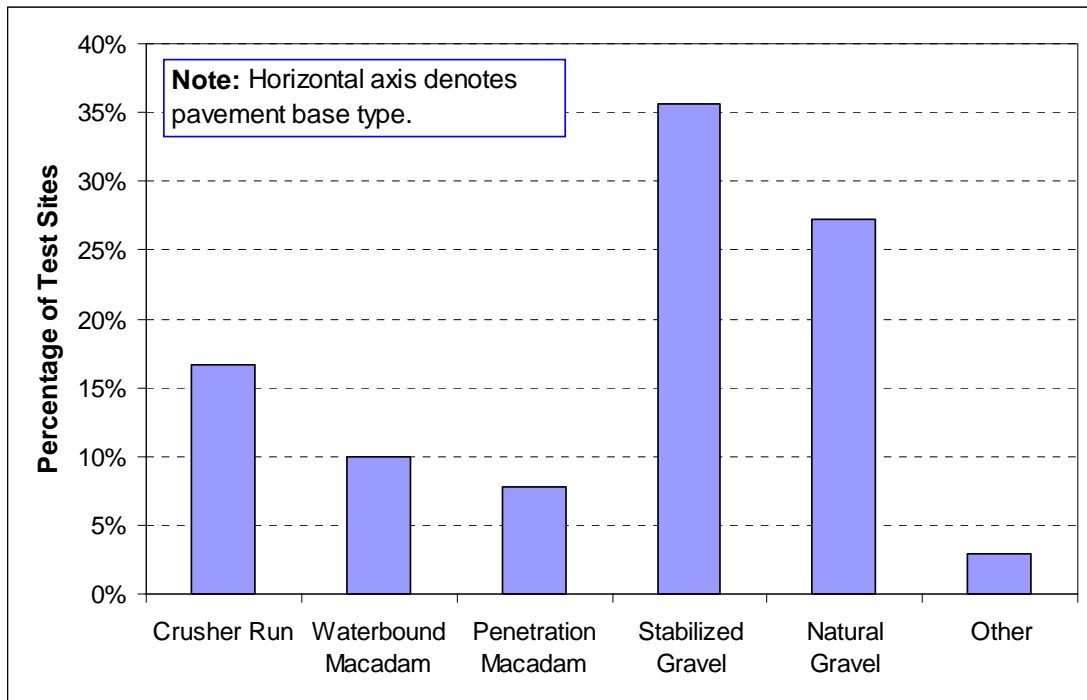


Figure 3: Percentage of pavements with different bases evaluated by Burrow (1975)

During the late 1950s to early 1960s, the TRD started experimenting with different particle gradations and construction methods for crusher run in an attempt to achieve higher densities and hence higher internal friction and strength. Eventually a construction process was developed in which the fines (minus 0,075 mm material) could be utilised as lubricant during the final wet compaction process. In this process, excess fines were extracted and discarded, in order to achieve a densely packed stone matrix. This compaction process became known as “slushing” and although it achieved an increase in density of only 3 to 4 per cent over that reached during the normal compaction phase, the overall result was a material with significantly higher shear strength. To achieve this state, a cemented subbase was required, since this layer provided a strong, water resistant “anvil” on which the final compaction phase could be executed.

The TRD and the National Department of Transport (NDOT) started applying this newly developed crusher run specification on their heavier pavement designs and soon observed that it exhibited a remarkable ability to handle the heaviest traffic loads, was quite impervious to water ingress, and even performed relatively well if it became wet. However, it was also noticed that if it was poorly supported, this material would tend to lose its high density and revert back to the behaviour and

performance of normally compacted crusher run. This observation further strengthened the consideration that it must be well supported, not only for construction purposes but also to maximise its service life. In order to ensure good performance, even under wet conditions, it was decided to apply a strict plasticity specification. This philosophy and practice started filtering through to other road authorities in South Africa.

It was soon realised that a superior material had been developed, and consequently the National and Provincial roads departments and the CSIR decided that it should have a name that could distinguish it from the familiar crusher run. During the late 1970s the name "Graded Crushed Stone" or "Crushed Stone" was agreed upon and since then indicated as such in the TRH (Technical Recommendations for Highways) and TMH (Technical Methods for Highways) documents^v. Over time, the specifications for this class of material evolved into two primary types. These were:

High Quality Graded Crushed Stone (G1)

The material consisted solely of high quality continuously graded fresh crushed rock material and had a Plasticity Index (PI) specification of zero to slightly plastic. It was typically compacted in a dual phased process, utilising the final slushing process, to a density specification of 86 to 88 per cent of Apparent Relative Density (ARD) (and variations of it) or of "solid density", as it became known because of the type of laboratory test involved in determining the 100 per cent mark.

Lower Quality Graded Crushed Stone (G2)

This material also consisted of a continuously graded crushed rock but allowed for fines derived from sources other than the crushed rock parent material, and sometimes even a natural gravel blend (Maree, 1982). It was typically only compacted to 98 to 100 percent of Mod. AASHTO. The material was also not slushed to the same extent as G1 material. It also has a more relaxed specification for the Plasticity Index.

During the late 1970's, the effect of the difference in specification and construction procedures on the behaviour and performance of the two types of Crushed Stone materials was not clear. It will be shown in Section 3 that the HVS investigations were instrumental in quantifying and qualifying the differences between these two material types.

2.2 DESIGN PRACTICE BEFORE HVS TESTING ON G1 MATERIALS

This subsection describes the approach to the design of Crushed Stone base pavements prior to the HVS development work on G1 materials. In this discussion, the focus is mainly on the higher traffic classes (i.e. with a cumulative traffic demand greater than 3 million standard axles, or MISA), as it is here where the impact of HVS investigations on G1 materials is believed to be greatest.

^v Although G1 and G2 type materials are generally referred to as "Crushed Stone", the TRH4 and TRH14 documents refer to these materials as "Graded Crushed Stone". To facilitate easier reading, the more concise term "Crushed Stone" will be used in this document.

HVS testing of pavements with Crushed Stone base types took place mainly between 1978 and 1982 (Maree, 1982; Kleyn and de Beer, 2004)*. The analysis and documentation of the findings of these tests took some time and the main impact of the HVS test findings on G1 materials occurred after 1982.

The state of design practice prior to 1982 is formally described in TRH4 (1978), TRH4 (1980) and, specifically in the former Transvaal Province (which included Gauteng, Limpopo, Northwest and Mpumalanga provinces), in the TRD Pavement and Materials Design Guide of 1978 (Guide L1/78). At this time, pavements with higher traffic volumes were typically grouped according to the traffic classification shown in Table 1.

TRH4 (1980) introduced a new traffic classification system using the “E” classes that are still in use today, albeit in an evolved format. The traffic classifications used in TRH4 (1980) are summarized in Table 2, and already reflect the need to accommodate higher traffic demands.

Table 1: Traffic Classification for Higher Traffic Classes, According To TRH4 (1978)

Traffic Class	Cumulative E80/Lane over the Design Period	Description
VI	1 to 3 million	Arterial roads with high traffic volumes; freeways with moderate traffic; industrial roads with low volumes of heavily laden vehicles; City arterials with heavy industrial traffic.
VII	3 to 10 million	Major arterial roads with very high traffic volumes. Freeways with moderate traffic and many tandem axles.
VIII	> 10 million	Heavy industrial haul routes with a high volume of laden heavy vehicles (generally tandem axles)

Table 2 Traffic classification for higher traffic classes, according To TRH4 (1980)

Traffic Class	Cumulative E80/Lane over the Design Period	Description
E2	0.8 to 3 million	Medium volume of traffic; few heavy vehicles
E3	3 to 12 million	High volume of traffic and/or many heavy vehicles
E4	12 to 50 million	Very high volume of traffic and/or a high proportion of fully laden heavy vehicles

* The HVS tests on graded Crushed Stone base pavements are discussed in detail in Section 3.

The L1/78 guide which was used by the TRD around 1980 had 5 traffic categories. The highest two categories were for cumulative traffic of 1 to 3 and 3 to 10 million standard axles (MISA). *There were no pavement designs suggested for design traffic greater than 10 MISA.*

The general attitude of researchers and pavement designers towards the use of high quality Crushed Stone materials for these types of traffic demand is best summarized in a document prepared in 1980 by the Committee on Pavement Type Selection for the National Transport Commission (Freeme et al., 1980). This document, entitled "The Economics of Pavement Type Selection", compared the cost effectiveness of various pavement types, including bitumen, tar, crushed rock and concrete base pavements. The following statement, quoted from the introduction, well expresses the attitude towards the use of crushed rock base pavements:

"Only pavements of approximately equal traffic carrying capacity are economically compared in this document. Therefore in the high traffic range (12 to 50 million standard axles over 20 years), only bitumen base pavements are compared with concrete pavements, even though indications are that other pavement types (such a crushed-rock base pavements) may be potentially capable of carrying these high repetitions of axle loads in certain areas of South Africa. It is considered that insufficient reliable performance data are currently available to make this comparison."

Thus for the high traffic demands of 12 to 50 MISA (i.e. the E4 traffic class, as defined in Table 2), only concrete and bitumen treated base pavements were considered in the economic analysis presented. The pavement structures considered for the E4 traffic class are summarized in Figure 4.

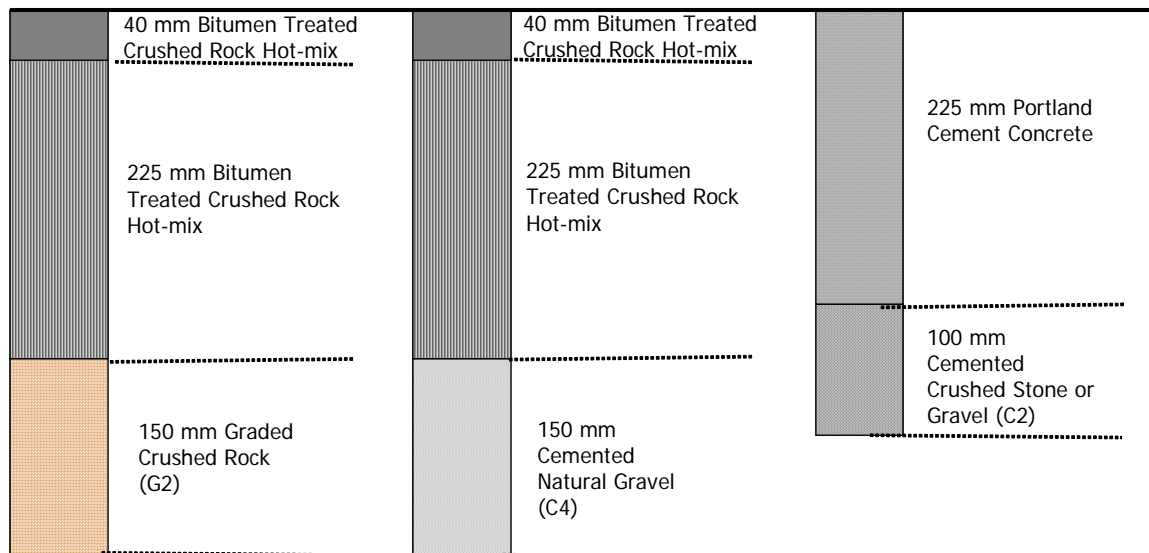


Figure 4: Designs alternatives considered in 1980 for traffic demands of 10 to 50 MISA (after Freeme et al, 1980).

* Underlining is not part of the original source document (Freeme et al, 1980);

The information contained in Figure 4 is important, since it explicitly defines the alternatives to the use of G1 base pavements, prior to the publication of findings of HVS tests and development work on G1 bases.

In the economic comparison of structures for the lighter pavement class (those suited for 3 to 12 MISA), Crushed Stone base pavements *were* considered together with bitumen and concrete base pavements. As expected, the Crushed Stone base pavements proved most cost effective, and the investigators concluded (Freeme et al, 1980):

“For pavements with traffic in the range of 3 to 12 million standard axles (E3 class) pavements with a crushed-rock base and cemented subbase appear to be significantly cheaper than bituminous and concrete pavements.”

For the E4 traffic class (12 to 50 MISA), the economic study of the pavements shown in Figure 4 suggested little difference in the present worth of costs of the bitumen and concrete base structures. Consequently, Freeme et al (1980) noted in their synopsis that there is little significant difference in cost between concrete and bitumen base pavements, adding again *“crushed-rock and tar base pavements are currently not recommended for carrying this very heavy traffic.”*

3 HVS INVESTIGATIONS ON G1 BASE PAVEMENTS

3.1 BACKGROUND

Accelerated testing of pavement structures with the Heavy Vehicle Simulator (HVS) first started in 1969 (Marais et al, 1982; Van Vuuren, 1972). Over approximately the next eight years, the HVS concept was refined and in 1977, the former Transvaal Roads Department (TRD) commissioned a new generation HVS for evaluation of departmental pavements and for development of pavement design technology.

One of the first objectives of HVS testing carried out by the Roads Department was to investigate the ability of high density graded Crushed Stone (G1) base pavements to carry heavy traffic (Marais et al, 1982). Specifically, there was uncertainty about the ability of G1 base pavements to accommodate traffic in the range of 12 to 50 MISA (the "very high", or E4 traffic category). Another objective was to gain an understanding of the behaviour of G1 materials and of the "inverted" pavement structures (i.e. those with an unbound granular base, supported by a stabilized subbase) in which they were commonly used.

It is important to note that G1 base pavements were a locally relevant technology not well refined at that stage. In particular, and as discussed in Section 2, there was not enough confidence at that stage to use high quality Crushed Stone bases for pavements in the E4 traffic category. This general lack of confidence was exacerbated by the premature failures on Road S12, a Crushed Stone and Stabilized Crushed Stone base pavement constructed in early 1970 (Marais et al, 1982, Kleyn and de Beer, 2004).

Investigation of the behaviour and performance of G1 base pavements through HVS testing was thus a necessary and cost-effective investigation method, specifically for the following reasons:

- Since the use of high quality Crushed Stone base was not actively being investigated in other countries, there was little information that could be gained from overseas research and development work. Thus there was a definite need to perform assessment and validation work within South Africa.
- Although not clearly stated at the time, there was a hypothesis that G1 base pavements could not accommodate traffic in the 12 to 50 MISA range. Evaluating this hypothesis provided a clear objective to HVS testing on G1 base pavements.
- To develop the necessary confidence for using G1 base pavements for traffic demands of 12 to 50 MISA without the benefit of HVS testing would take at least 15 years of long-term pavement performance monitoring. HVS testing provided a means to greatly accelerate this information gathering process, and was thus the most cost effective method of investigation in this case.

3.2 HVS TESTS CONDUCTED ON G1 BASE PAVEMENTS

HVS investigations were conducted on seven G1 base pavements between 1978 and 1982. The majority of these were conducted in the former Transvaal province, with one test being conducted near Mooi River in Kwazulu-Natal, and another near Koeberg in the Western Cape. The seven pavements tested were:

- Road S12, near Benoni (Gauteng)
- Road 1955, Section K17 near Ogies (Gauteng)
- Road 1955, Section K11 near Ogies (Gauteng)
- Road P157/1 near Olifantsfontein (Gauteng)
- Road P157/2 near Johannesburg International Airport (Gauteng)
- Road N3, near Mooi River (Kwazulu-Natal), and
- Road TR77/1, near Koeberg (Western Cape).

Details of these seven investigations, with the main observations and conclusions gained from each investigation, are provided in Appendix A.

3.3 SUMMARY OF FINDINGS

The following conclusions were made based on the HVS tests listed in the preceding subsection*:

- Pavements with high quality Crushed Stone bases (i.e. materials that can be classified as G1) are capable of accommodating traffic demands of up to 50 million standard axles.
- The optimum thickness for a G1 base layer on a cemented subbase is 150 mm.
- If a pavement with a Crushed Stone base is maintained with resurfacings at appropriate intervals, the pavement can provide service for an indefinite time.
- For pavements with a G1 base on a cemented subbase, it was found that the damage, or equivalency, exponent “n” has a value of approximately 3, and not 4.2 as was commonly accepted at the time.
- The moisture content of the G1 base is a determining factor in the bearing capacity of G1 base pavements. The quality of the Crushed Stone base becomes even more apparent when moisture enters the layer.
- The high quality, high density Crushed Stone (G1), placed on a thick cemented subbase (200 mm or more), showed the least permanent deformation under loading and was also the least sensitive to moisture.
- A more open graded and less dense Crushed Stone was less stable under loading and also acted as water carrier to distribute water to the rest of the pavement structure (this observation refuted the understanding – prevalent

* These conclusions are based on statements made in several technical documents that are summarized and discussed in Section 3.4.

under many researchers at that stage – that more open graded Crushed Stone layers are less sensitive to water since they do not retain water for long periods).

- There was a reasonable correlation between the calculated and observed structural capacities for Crushed Stone layers. This confirmed the appropriateness of the mechanistic design method (which was still being developed at that stage) to analyze these types of structures.

3.4 TECHNOLOGY TRANSFER FOR HVS INVESTIGATIONS

The findings of the HVS investigations on G1 base pavements were presented at regular HVS steering committee meetings, and were published in several reports and at local and overseas conferences[♦]. Some of the most influential of these publications were the following:

Maree (1982): "The behaviour of pavements with Crushed Stone base layers in HVS tests"

This document provided a detailed description of the tests performed on G1 bases (all of which are summarized in Appendix A), and summarized the observations and conclusions. Amongst the conclusions was the following statement:

"HVS tests on a variety of pavement structures with crushed stone bases have shown that these pavements are capable of accommodating very heavy traffic. Up to 50 million E80's can be accommodated by a high quality crushed stone base (G1a)."^{*}

Marais et al (1982): "The impact of HVS testing on Transvaal pavement design"

This paper, presented at the 1982 Annual Transportation Convention (ATC), provided a summary of the HVS test program carried out in the former Transvaal province. The paper summarized the main findings of the HVS tests conducted between 1977 and 1981. The paper clearly showed the impact of HVS tests and investigations on the understanding of pavement behaviour, and stated that the test results have impacted on the design catalogue, in a manner that lead to more cost effective designs. With regards to the performance of G1 bases, this paper contained the following statement:

"It has been confirmed that a high-quality crushed-stone base (G1a) which is well supported on a cemented subbase, is able to carry the heaviest traffic."

Maree, 1982: "Aspects of the design and behaviour of pavements with unbound granular base layers".

This dissertation provided a comprehensive outline of the HVS tests carried out on different types of granular base pavements. The dissertation convincingly showed that G1 materials can accommodate traffic in the 12 to 50 million standard axle range. It also established a design methodology for Crushed Stone bases layers, which has since been widely implemented through the South African Mechanistic

[♦] The fact that the HVS test results were implemented in the TRD design specifications as soon as they became known (and often before they were officially published), also assisted greatly in the technology transfer;

^{*} Translated from Afrikaans;

Design Method. A mechanistic evaluation of a pavement with a G1 base on a cement stabilized subbase showed that the structure is capable of accommodating in excess of 50 million standard axles, provided that the surfacing is maintained at appropriate intervals.

The structural capabilities of G1 base, cemented subbase pavements was formalized through the changes in the design catalogues over the period 1978 to 1985, when most of the tests on G1 base pavements were performed and during which most of the findings were published in South Africa and overseas.

Mitchell and Walker, 1985: "The economics of pavement type selection":

Perhaps the most convincing indication of the contribution of the HVS tests to the acceptance of G1 base pavements for higher road categories, comes from the paper entitled "The Economics of Pavement Type Selection", published by Mitchell and Walker in 1985 (Mitchell and Walker, 1985). This paper has a similar title and in essence the same content as the 1980 study on the economics of pavement selection (Freeme et al, 1980) which is quoted from in section 2.2. However, the later publication (Mitchell and Walker, 1985) clearly shows a change in the confidence for using G1 base pavements for the 10 to 50 MISA traffic class.

In the 1985 publication (Mitchell and Walker, 1985), as in the 1980 study (Freeme et al, 1980) different pavement types are compared for the 12 to 50 MISA traffic class. However, in the 1985 publication, unlike the 1980 publication, G1 base pavements are included, as shown in Figure 5. This clearly shows the increase in confidence for using these types of pavement structures for high traffic demands. The authors also clearly explain the basis for pavement selection:

"These structures have all been thoroughly tested with the Heavy Vehicle Simulator which has shown that they are capable of withstanding the upper range of E4 traffic (30 to 50 million E80s)"

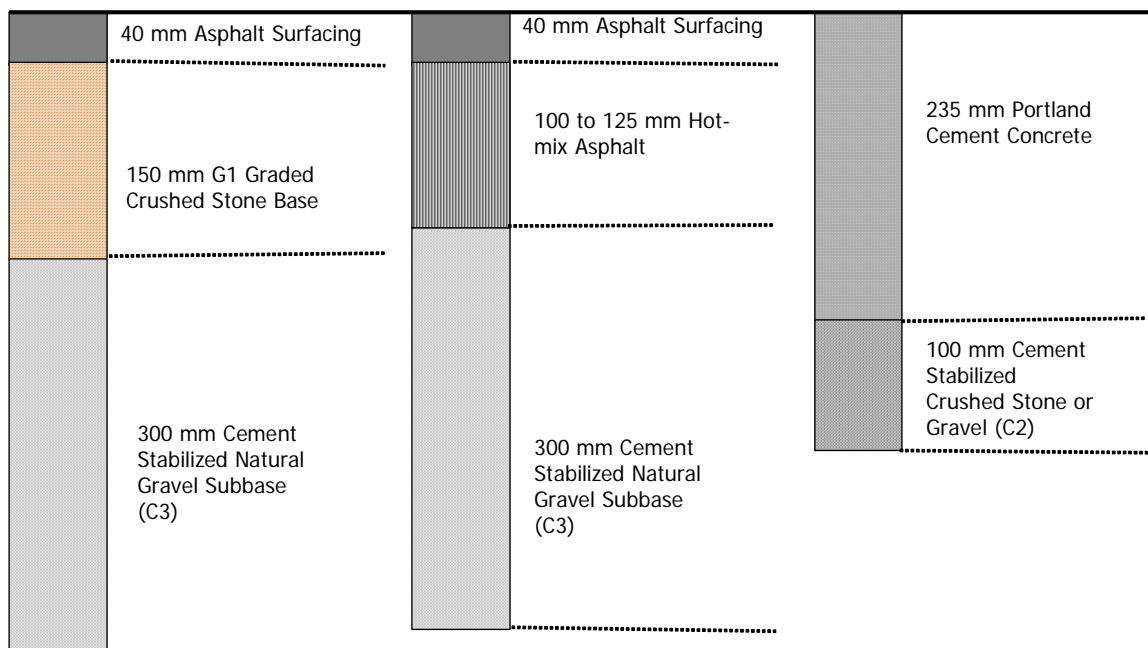


Figure 5: Designs alternatives considered in 1985 for traffic demands of 10 to 50 MISA (Mitchell and Walker, 1985).

4 THE IMPACT OF THE HVS INVESTIGATIONS

4.1 SUMMARY OF THE G1 DEVELOPMENT PROCESS

As with all complex and influential technologies, the development of G1 base pavements for high design traffic situations took more than a decade to complete to a level where it was readily accepted by pavement design practitioners. Some of the key impacts on the G1 development process are summarized in

Figure 6. Each of these impacts is described in earlier sections of this report. The two main phases of the development process are summarized below:

Early 1960's to early 1970's: Establishment and Refinement of the G1 Concept

During this period, the TRD experimented with the use of high quality, high density Crushed Stone material (see Section 2.1 for details). These experiments resulted in refined specifications and a specific construction process for Crushed Stone materials. During the 1970's other client bodies such as the National Department of Transport and the Cape Provincial Administration started participating in the G1 development process. By 1978, the G1 classification was established for this type of material, and designs incorporating G1 bases were included in the TRH4 (1978) document.

Field experiments with G1 materials proved that a high density Crushed Stone on a cemented subbase can accommodate fairly high traffic demands. However, at that stage few roads needed to accommodate traffic demands in the range of 12 to 50 MISA. As a result, there was insufficient confidence in the use of G1 base pavements

for the “very high” design traffic class, and few or no pavement engineers would have recommended the use of a G1 base pavement for a 12 to 50 MISA design in the late 1970’s.

The understanding of G1 material behaviour and performance was considerably enhanced by the analytical work done by Maree (1978) on Crushed Stone materials. However, G1 technology was still not highly regarded, and there was considerable controversy over the boundaries in which G1 technology could efficiently operate. Based on information provided by Maree (a primary author of the 1980 TRH4 draft document), there was also controversy at the time about the use of G1 base pavements for the 3 to 12 MISA traffic classes. Thus, although G1 base pavements were being implemented on several projects, the formal inclusion of this pavement type in the South African design guidelines was still under scrutiny. The extension of the G1 concept to areas other than the former Transvaal province, where it was fairly well established by 1978, was also stunted by scepticism about the feasibility of using G1 base pavements in areas other than the Witwatersrand, and in particular in the wet regions of the Southern Cape and Kwazulu-Natal.

1978 to 1985: Validation and Refinement

During this period, HVS investigations were performed on several G1 base pavements (summarized in Section 3 and in Appendix A). *The findings of these investigations proved instrumental in refining G1 design and construction practice. Most important, it validated the use of G1 base pavements for the 12 to 50 MISA traffic class, and provided the information needed to calibrate a design method for this type of material.* These impacts, as well as the dissemination of the information associated with the HVS investigations, greatly enhanced the standing of G1 technology in South Africa.

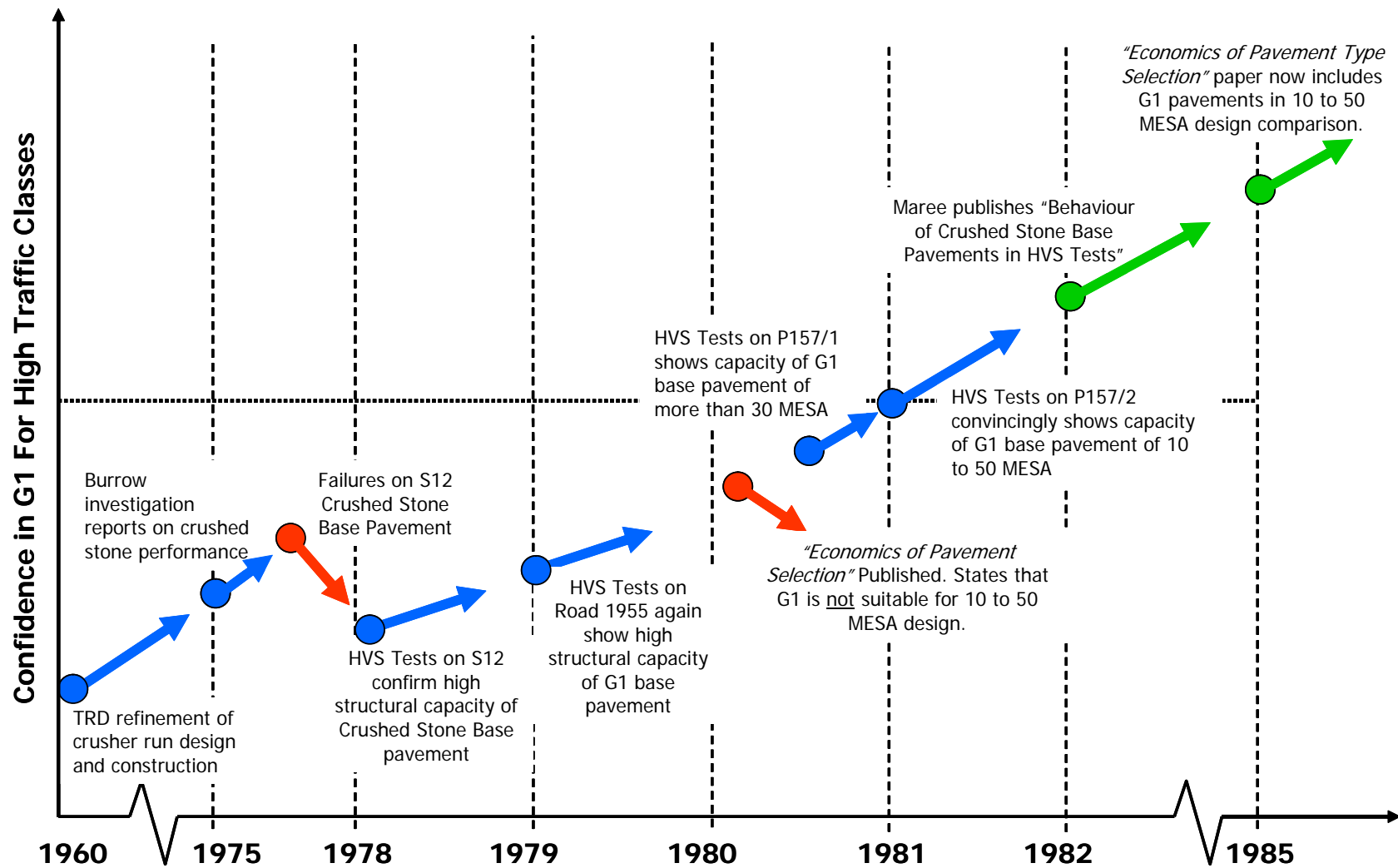


Figure 6. Summary of the evolution of G1 pavements for use in high traffic designs

4.2 CONTRIBUTION OF HVS INVESTIGATIONS

Refined G1 technology was the result of a sustained development effort by the Transvaal Roads Department and the National Department of Transport, with additional contributions by other provinces (most notably the Cape Provincial Administration). These efforts were largely based around specifications that evolved over time and as more and more projects that incorporated G1 bases were being completed.

The informal but sustained efforts to refine G1 material design and construction ripened G1 technology to the point where a design methodology could be formalized through HVS investigations that focussed specifically on Crushed Stone bases (G1 and G2 class materials). The concept of the HVS investigation acting as a focusing mechanism to refine and finalize G1 pavement technology is illustrated in Figure 7.

The HVS investigations on G1 base pavements contributed to the overall development of G1 technology in the following general ways:

- HVS investigations on G1 base pavements were the first formalized experiments in which G1 behaviour and performance data was collected.
- Because of the accelerated and organized nature of HVS investigations, the HVS tests acted as a focal point and catalyst to accelerate and drive the development of a design method for unbound pavement layers.
- Regular meetings of the HVS steering committee and the published findings of HVS investigations became outlets at which technology transfer to practitioners was established. This contributed greatly to the acceptance of G1 technology as part of South African pavement design and construction practice.

It should be clear from the preceding discussion and from Figure 7 that the HVS was not solely responsible for the development of the G1 technology that was eventually implemented on many roads across South Africa. Rather, the HVS was a key contributor to the refinement and delivery of the G1 technology that had been informally and empirically developed before 1978.

The HVS investigations thus shared in the impact that G1 technology had on pavement design and construction practice, as well as on science and technology (S&T) excellence in South Africa. Specific impacts of the HVS investigations on G1 base pavements are summarized in the following sections[♦]. In these sections, a distinction is made two types of benefits. These are (i) Direct Benefits, for which the impacts can be evaluated in economic terms; and (ii) Indirect Benefits, for which the impacts are difficult to assess in economic terms.

[♦] These impacts were also discussed in section 3. However, they are formulated here specifically to facilitate the economic evaluation of benefits derived from HVS investigations (the economic benefits derived from these impacts are discussed in Section 6).

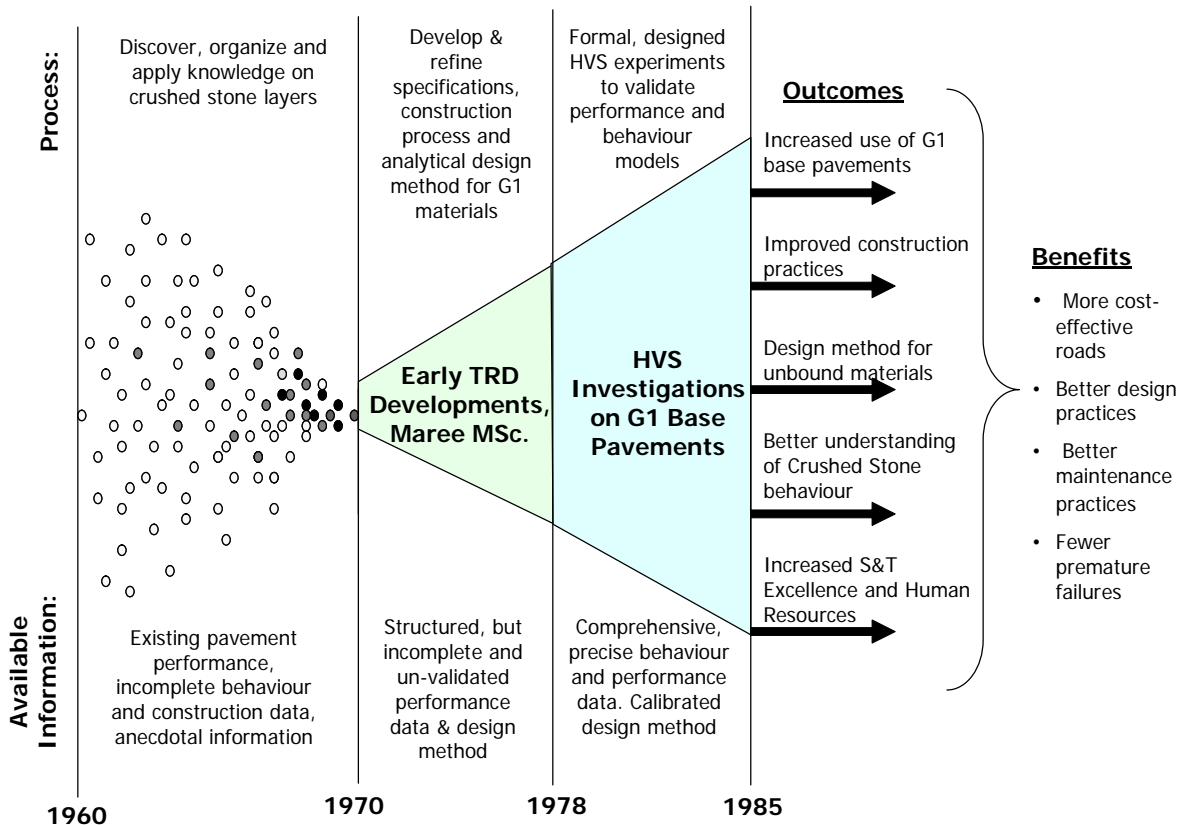


Figure 7: The contribution of HVS Investigations to the development of G1 technology (concept after Ounjian and Carne, 1987; and Horak et al, 1992)

4.3 DIRECT IMPACTS OF HVS INVESTIGATIONS

- The suitability of G1 base pavements for the 12 to 50 MISA design traffic class was clearly proven

Before HVS testing started, there was doubt whether a pavement with a Crushed Stone base was suitable for this high traffic demand, and before 1980 few designers would have prescribed a G1 base pavement for a 12 to 50 MISA design traffic situation. By 1982, the HVS investigations had provided conclusive evidence that a G1 base on a thick cemented subbase could sustain up to 50 MISA, provided that proper drainage is provided and the surfacing is well-maintained. A specific result of this impact was the extension of the Gautrans pavement design catalogue from an upper limit of 10 (before HVS test findings became known) to 100 MISA after HVS findings were assimilated.

The relative contribution of HVS investigations to this impact is estimated to be around 80 per cent. This contribution is based on the fact that HVS testing, owing to its accelerated nature, vastly accelerated the gathering of evidence to prove the suitability of G1 base pavements for the 12 to 50 MISA traffic class. To gather this evidence without access to HVS test results would have required an extensive long term pavement performance experiment that would have required sustained funding for at least a decade.

- **The low sensitivity of a high density G1 material to moisture proved that a G1 base pavement can be used in wet climate zones**

HVS investigations on G1 base pavements showed that a high density G1 material is relatively impervious and not highly sensitive to moisture. As a result, G1 base pavements were considered suitable for use in the wet climate zones of South Africa. In 1985, G1 base pavements were included in the TRH4 (1985) pavement design catalogue for wet regions (even for a 12 to 50 MISA design traffic class).

The relative contribution of HVS investigations to this impact is estimated to be around 80 per cent. This contribution is again based on the accelerated nature of HVS testing, and also on the controlled nature of HVS tests, which allowed precise monitoring of moisture in the different test pavements. To gather such evidence without access to HVS test results would have required an extensive long term pavement performance experiment that would have required sustained funding for at least a decade.

- **For Crushed Stone layers on cemented subbases, the damage equivalency exponent “n” was proven to be lower than 4.2, and closer to 3 (on average)**

Before the HVS investigations on G1 base pavements were completed, the exponent used to convert traffic loads to equivalent standard axles (E80's) was 4.2, as suggested by the AASHTO road test. The HVS tests showed that the equivalency exponent was dependent on pavement type and condition (especially moisture content) and load magnitude and could range from 1 to 5 for G1 base pavements, with an average value of around 3.

The result of this finding is that, for the same traffic spectrum, the design traffic requirements would be lower on a G1 base pavement than it would for (say) a cemented base pavement which has a higher equivalency exponent. This means that, with the use of a reduced equivalency factor, the design traffic requirements for many pavements with G1 bases were lower, resulting in a reduced and more cost-effective pavement structure.

The relative contribution of HVS investigations to this impact is estimated to be around 80 per cent. This contribution is again based on the accelerated and precise nature of HVS testing and information gathering. Without the benefit of precisely controlled loads and knowledge of applied number of repetitions, the evaluation of the equivalency exponent would not be feasible.

- **The design methodology for Crushed Stone layers, coupled with the validation through HVS investigations, showed that a thickness of 150 mm is optimal for G1 layers.**

Prior to the HVS investigations on G1 base pavements, there was a tendency to use thicker Crushed Stone layers for higher traffic demands. This approach stemmed from the AASHTO philosophy which largely strove to protect the subgrade through the use of a thicker pavement structure.

The development of the "Safety Factor" method for designing Crushed Stone layers, and its subsequent validation through HVS testing, provided proof that thicker Crushed Stone layers could be more prone to failure, owing to the reduction in the compressive stress needed to induce high shear strength in such materials. The resulting optimization of layer thickness has obvious economic impacts.

The relative contribution of HVS investigations to this impact is estimated to be around 30 per cent. This contribution is based on fact that the optimization of G1 layer thickness was largely based on analytical evaluations of Maree (1982). However, the HVS investigation contributed by validating the theory and by providing data to refine the design methodology for Crushed Stone layers in South Africa.

- **The difference between the performance of a high density (G1 class) base and a lower density (G2 class) base was clearly proven**

Before the findings of the HVS tests on G1 base pavements were published, there was a theory - prevalent amongst some researchers - that a more open graded granular layer is less sensitive to moisture. The HVS tests on G1 and G2 materials conclusively showed that a higher density Crushed Stone is less sensitive to moisture and provides better protection against moisture for the other pavement layers. This finding contributed to refine specifications and construction methods for G1 materials.

The relative contribution of HVS investigations to this impact is estimated to be around 40 per cent. This contribution is based on fact that the HVS tests were instrumental in proving the difference between the high quality, high density G1 material, and the lower density G2 (or G1b) materials. However, the assigned contribution also recognizes other contributions stemming from the experiences of the National Department of Transport and other provincial administrations in the development and refinement of specifications for G1 materials.

4.4 INDIRECT IMPACTS

The impacts summarized in Section 4.3 have economic benefits that may be directly quantifiable, as will be discussed in Section 6. Apart from these benefits, numerous other benefits resulted from the HVS development efforts between 1978 and 1982. These benefits are not readily quantifiable in economic terms, but are no less important for the people of Gautrans and South Africa. These benefits include the following:

- **Political benefits**

As explained earlier, the TRD was a pioneer in the early development of G1 technology. The use of G1 materials for high design traffic situations was initially confined to the Witwatersrand area, where contractors were gaining experience in the somewhat specialized production and construction technique required for G1 layers.

Experience within the TRD suggested that G1 base pavements, if properly constructed and maintained, were capable of accommodating traffic in the range of 12 to 50 MISA. However, since this practice was significantly different to that used in most overseas countries as well as in other local government agencies, the TRD endured frequent criticism for their use of G1 base pavements for such design traffic situations. The proof of the structural capacity of G1 pavements, provided by the HVS, had a positive political impact.

- **Contribution to Science and Technology Excellence**

The HVS investigations on G1 base pavements were perhaps the first structured and sustained effort to analyze and master a specific pavement technology that would provide less expensive and longer lasting pavements than those designed and constructed with the accepted methods of that time. As a result of these efforts, the academic output (in terms of publications in journals and at conferences) increased significantly from 1978 to 1985. Since many of these publications reached an international audience, the HVS programme was one of the key contributors to the establishment of South Africa as a leader in the field of pavement design and construction technology (specifically with regards to unbound base layer pavements).

The HVS investigations on G1 base pavements contributed to the career development of several prominent researchers in the field of pavement design and construction. Thus, apart from the direct employment opportunities created by the HVS investigations, the HVS investigations on G1 material and its impact on key technical publications such as the TRH4 and TRH14 documents were instrumental in creating a critical mass of skilled engineers who could further and implement G1 technology.

- **Development of the HVS Concept**

To date, a number of HVS machines have been sold to overseas government agencies. The HVS tests conducted between 1978 and 1982 were instrumental in the refinement of the HVS concept and directly contributed to the eventual sale of the HVS and its associated technologies to overseas agencies.

4.5 SUMMARY

In this section, the impact that the HVS investigations on G1 base pavements had on pavement design and construction technology in South Africa was discussed. Key elements of this discussion include:

- It was noted that the development of the technology for the design and construction of G1 base pavements was an extended process which was largely initiated by the former Transvaal Roads Department (TRD).
- The development of HVS technology was classified into two phases. These were: (i) a basic technology development phases from the early 1960's to roughly 1978, and (ii) a validation and refinement phase (1978 to 1985), in which the HVS played a pivotal role.

- There were several contributors to the successful implementation of G1 technology. The HVS development programme was one of these contributors, and played a key role in validating the earlier analytical work of Maree (1978) and others. It also provided an organized structure to the documenting and validation of the performance of G1 base pavements.
- The key impacts of HVS investigations on G1 base pavements were summarized as:
 - 1) The suitability for G1 base pavements for the 12 to 50 MISA design class was clearly proven;
 - 2) The feasibility of G1 base pavements in wet regions was proven (largely owing to the impervious and low moisture sensitivity of G1 base layers);
 - 3) It was found that the damage exponent (or n-value) of pavements with a G1 base over a thick cemented subbase was close to 3, and not 4.2, as was commonly assumed;
 - 4) It was proven that a 150 mm thick G1 layer is optimal for G1 base layers;
 - 5) The difference between the high quality G1, and lower quality G2 material was clearly shown;
- Since the HVS test programme was only one of the contributors to the successful implementation of G1 technology, any evaluation of economic benefits should take into account the relative contribution of other role players. For each of the identified impacts, a relative contribution percentage was assigned and discussed[♦].
- It was noted that the HVS investigations also had other impacts, such as those relating to Science and Technology development, but that these cannot be readily evaluated in economic terms.

A consideration of the main impacts of the HVS investigations show that, over the long term, these impacts contributed greatly toward the effective and accelerated acceptance of G1 pavement technology in South Africa. It also contributed greatly to the establishment of South Africa as one of the world-wide leaders in pavement design technology.

After consideration of the identified impacts, and specifically of the data and assumptions needed to convert these impacts to benefits in economic terms, it was decided to combine these impacts into the following main benefits:

Benefit 1: Increased use of G1 Base Pavements for higher design classes and wet regions

Benefit 2: Use of a 150 mm maximum thickness for G1 base layers

Benefit 3: Improved maintenance and construction practices

The assessment of the economic benefits provided by these main benefits is discussed in Section 6.

[♦] These contribution ratios were validated and adjusted through interviews – conducted by the author – with industry experts. This aspect is discussed in Section 6.

5 THE COST OF HVS INVESTIGATIONS ON G1 BASE PAVEMENTS

5.1 GENERAL

Estimation of the costs of the G1 development programme involves the retrieval of cost information that is nearly 25 years old. The cost estimation is further complicated by the fact that several agencies contributed to the G1 development programme, namely Gautrans (then Transvaal Roads Department, or TRD), the National Department of Transport, and the Division of Roads and Transport of the CSIR (Transportek)*.

The approach adopted for this benefit assessment study aims to take into account all possible costs associated with the G1 development programme, while at the same time attempting to isolate the contributions made by Gautrans. The cost estimation relies primarily on two sources of information. These are:

1. The overall HVS operational budgets for the former Transvaal Roads Department, in the years when the most influential HVS tests on G1 base pavements were performed.

These figures were obtained from Transportek financial records and describe the total contribution that was forthcoming from the TRD to finance HVS operational costs. Since not all of these funds were necessarily allocated to G1 development work, the proportion of funding allocated to HVS tests was based on the number of days of the year in which G1-specific HVS tests were in progress.

2. The average cost per HVS load repetition, estimated at the time of G1 development work.

These figures were obtained from Transportek internal records (Freeme, 1979) and provide an estimate of the cost per equivalent standard axle (E80) load repetition. In 1979, the cost per E80 repetition was calculated at R0.0037, based on the total running cost for that year and the total number of repetitions that had been applied to various test sections.

For the tests conducted by the Gautrans HVS machine, the cost of testing was based solely on the TRD budget for operational costs. For tests not conducted by the Gautrans machine, the costs were based on the average cost per E80 applied by the HVS.

Items 1 and 2 noted above do not account for the human resource cost involved in the analysis and documenting of findings. This important cost element is difficult to determine, since it was at the time co-funded by the Department of Transport and CSIR, and most probably some of this cost was included in the HVS operational costs.

* At the time of the G1 development programme, CSIR Transportek was known as the National Institute for Transport and Road Research (NITTR)

The approach adopted for this study was to estimate the human resource cost related to data analysis and documentation, as a percentage of the operational cost for a HVS test. This approach ensures that tests which involved more repetitions and took longer to complete would have a greater analysis and documentation component. The estimate was then also verified through reference to the annual salaries of the various types of personnel involved in data analysis and documentation.

Another element to consider is the discount rate. This is specifically important for the cost per E80 repetition, which was estimated in 1979. Typically, this estimate would have to be escalated for the years 1980 to 1982 in which the other G1 tests were performed. However, 1982 estimates of the cost per repetition suggest a value of R0.0035 per E80 repetition (Freeme et al, 1982)*.

It thus seems that the actual operational cost per repetition did not escalate with inflation (which was very low around 1980), but stayed somewhat stable or perhaps decreased slightly. This is to be expected, since the first tests conducted around 1979 involved a lot of refinement and adjustments to the HVS machines. It is likely that these refinements increased the operational cost in the earlier development period (roughly 1970 to 1979), but paid off in later years when the earlier developments lead to a stable or decreasing operational cost. For this analysis, the cost per E80 repetition was thus fixed at R0.0037 for the years 1979 to 1982.

5.2 SUMMARY OF COSTS

For the assessment of the cost of G1 development work, the operational cost was first determined using the information sources noted in the previous section. Separate calculations were made for tests conducted by the Gautrans and other HVS machines. The operational cost was then increased to account for the human resource costs for data analysis and documentation.

The operational cost for tests on G1 base pavements, and conducted by the Gautrans HVS machine, is summarized in Table 3. As noted before, these costs are based on documented budget allowances for HVS operations in the indicated years.

The operational cost for tests conducted on G1 base pavements by HVS machines other than the Gautrans machine is summarized in Table 4. These costs were based on documented estimates for the average cost per E80 repetition. The operational costs for all tests are summarized in Table 5, based on the costs shown in Tables 3 and 4. Also shown in Table 5 is the estimated cost for data analysis and documentation, as a percentage of the operational cost.

* The source document for this estimate (Freeme et al, 1982) actually estimates the cost at 35 cents (i.e. R0.35) per E80 repetition. However, this is clearly an error, since the use of this figure would amount to more than R10 million for the years 1979 to 1981, while the documented HVS operational cost for January to September 1979 is only R450,000 for the entire HVS fleet. From this it is deduced that the figure provided by Freeme et al (1982) should be R0.0035 (which corresponds closely with Freeme, 1979), and NOT R0.35.

Table 3: Operational costs for HVS tests conducted by the Gautrans machine on G1 materials (1978 to 1980)

Financial Year	HVS Operational Budget	HVS Test	Test Duration (days)	% of Budget Allocated	Relative Cost
1978 to 1979	R 107,467.00	S12, Cloverdene	202	55%	R 59,475
	R 107,468.00	Road 1955, K17	158	43%	R 46,520
1979 to 1980	R 239,697.00	Road 1955, K11	50	14%	R 32,835
1980 to 1981	R 270,000.00	P157/1 Olifantsfontein	122	33%	R 90,247
	R 270,000.00	P157/2 Olifantsfontein	116	32%	R 85,808

Table 4: Operational costs for HVS tests conducted on G1 materials, by HVS machines other than the Gautrans machine

Year	Test	Equivalent E80's Applied	Operational Cost ¹
1981	N3, Mooi River (Kwazulu-Natal)	31.6 million	R 116,920
1981	TR77/1 (a), Koeberg (Western Cape)	11 million	R 40,700
1981	TR77/1 (b), Koeberg (Western Cape)	12.7 million	R 46,990

1. Assuming R0.0037 per E80 repetition for all years

Analysis of the costs in Tables 3 and 4 shows that the cost per E80 repetition of the Gautrans HVS machine is significantly lower (on average R0.0025 per E80) than R0.0037 cent per E80 repetition that is used for tests conducted by HVS machines other than the Gautrans HVS. This is to be expected, since the tests conducted by the Gautrans machine were all close to the CSIR centre where the machines were maintained and where first level processing of data was conducted.

Table 5: Operational cost summary, with estimated analysis and documentation costs

Year	HVS Test	Operational Cost	Analysis & Documentation Cost, as % of Operational Cost		
			10%	20%	30%
1978	S12, Cloverdene	R 59,475	R 5,947	R 11,895	R 17,842
1979	Road 1955, Ogies	R 79,355	R 7,936	R 15,871	R 23,807
1980	P157/1	R 90,247	R 9,025	R 18,049	R 27,074
1980	P157/2	R 85,808	R 8,581	R 17,162	R 25,742
1981	N3, Mooi River	R 116,920	R 11,692	R 23,384	R 35,076
1981	TR77/1 (a), Koeberg	R 40,700	R 4,070	R 8,140	R 12,210
1981	TR77/1 (b), Koeberg	R 46,990	R 4,699	R 9,398	R 14,097

For analysis and documentation cost estimated at 20 per cent of the operational cost, the total analysis and documentation cost for 1980 and 1981 is roughly R 76, 000. Based on Transportek remuneration records for this period, this sum would be roughly sufficient to provide for more than 80 per cent of the total annual salaries of a chief research officer, a data analyst (technical) and a chief technician for a two year period.

Analysis of the cost of operations of recent HVS tests has also shown that the analysis and documentation cost is consistently around 20 per cent of the operational cost. The 20 per cent allowance is therefore regarded as most appropriate for determining the overall cost of testing, analysis and documentation of findings.

The total cost for G1 development is summarized in Table 6 for various discount rate scenarios. In this table analysis and documentation cost was estimated at 20 per cent of the operational cost, and is included in the total development cost shown. Depending on the discount rate, the total estimated development cost in 1978 Rand varies roughly between R500, 000 and R575, 000.

The contribution stemming from Gautrans funding (i.e. for the first 4 tests shown in Table 6), varies roughly between R325, 000 and R360, 000, depending on the discount rate. Based on cost, Gautrans contributed roughly 60 per cent of the overall G1 development effort.

It is believed that, if the initiative, leadership and motivational efforts of Gautrans with respect to G1 development are taken into account, this figure understates the overall contribution of Gautrans to the understanding of G1 materials and its eventual adoption for the higher traffic classes.

Table 6: Total cost of G1 development for various discount rates

Year	Test	Total Development Cost	Present Worth in 1978, at a Discount Rate of:		
			4%	8%	12%
1978	S12, Cloverdene	R 71,370	R 71,370	R 71,370	R 71,370
1979	Road 1955, Ogies	R 95,226	R 91,564	R 88,172	R 85,023
1980	P157/1	R 108,296	R 100,126	R 92,846	R 86,333
1980	P157/2	R 102,970	R 95,201	R 88,280	R 82,087
1981	N3, Mooi River	R 140,304	R 124,730	R 111,378	R 99,866
1981	TR177/1 (a), Koeberg	R 48,840	R 43,419	R 38,771	R 34,763
1981	TR177/1 (b), Koeberg	R 56,388	R 50,129	R 44,763	R 40,136
Cost To Gautrans (1978 Rand)			R 358,261	R 340,669	R 324,813
Cost To DOT (1978 Rand)			R 218,277	R 194,911	R 174,765
Total Cost of G1 Development (1978 Rand)			R 576,538	R 535,580	R 499,578
Total Cost of G1 Development (2004 Rand)			R 1,598,433	R 3,961,338	R 9,511,998

Note: Total development cost assumes data analysis and documentation cost at 20 per cent of HVS operational cost;

To put the costs shown in Table 6 in a modern perspective, Table 6 also shows the cost of development in year 2004 terms. It should be noted, however, that this cost is highly dependent on the assumed discount rate (which was not constant between 1978 and 2004), and should be regarded as illustrative only.

6 ECONOMIC BENEFITS OF G1 DEVELOPMENT WORK

6.1 METHODOLOGY

Evaluations of the economic returns of research and technology development work are notoriously difficult to perform. An economic benefit can only be calculated if the outcome of a technology development effort can be compared to a scenario that would have existed had the development not been undertaken. Such an assessment includes a large element of uncertainty and subjective judgement. For example, no-one can state with certainty what direction the road-building industry would have taken in the absence of the HVS investigations on G1 base pavements. This is especially relevant in the case of a mature technology such as that of G1 material and its associated knowledge elements, which have been assimilated for several decades. Simply put: it is difficult for most South African pavement engineers to imagine a life without G1 material and the knowledge associated with it.

The methodology adopted for the evaluation of economic benefits takes this uncertainty into account, and is based on the framework established by other investigators concerned with assessment of the benefits of technology development work (ARRB, 1992; Swoveland and Cawdery, 1989). The methodology is shown schematically in Figure 8.

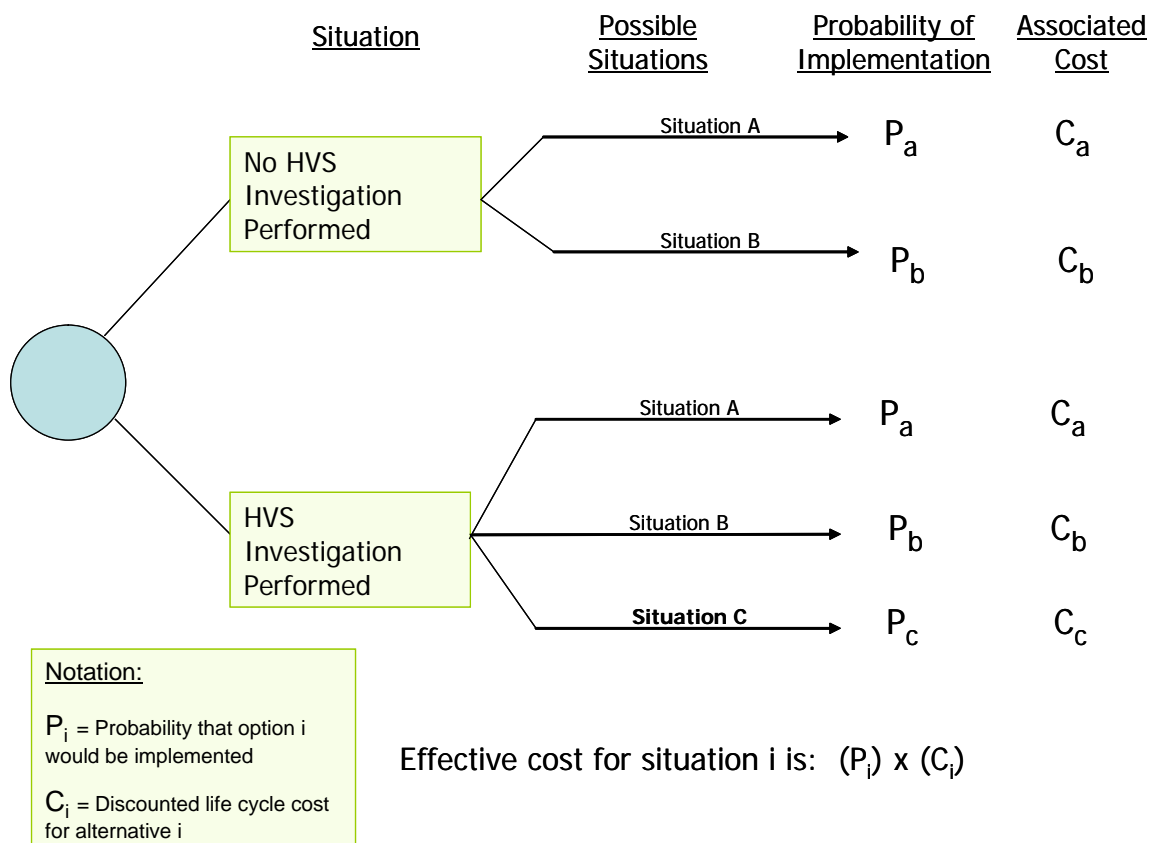


Figure 8: Methodology for evaluating the economic impact of G1 development work (based on ARRB, 1992).

Key elements of the methodology shown in Figure 8 are:

- The situation *with and without* the benefit of HVS investigation findings are assessed;
- The uncertainty of each situation being realized is acknowledged and accommodated by assigning a *probability* to each outcome;
- The cost of each outcome is determined and multiplied with the probability to obtain the *effective cost* for a given outcome.

Once the different outcomes and their associated costs are determined, the benefit of the development work is calculated by subtracting (i) the total effective cost of all options without the benefit of HVS investigations from (ii) the total effective cost of all options with the benefit of HVS investigations. The calculated benefit can then be used with the cost of the development to determine an economic indicator such as a benefit cost ratio or a rate of return.

The cost associated with the HVS investigations on G1 base pavements is summarized in Section 5. The main impacts and associated benefits that the HVS investigations on G1 base pavements had on design and construction practice in South Africa are summarized in Section 4, with additional background provided in Sections 2 and 3. In the summary of these impacts and benefits, care was taken to establish the status of the related design or construction aspect before and after the HVS investigation. This lays the foundation for the evaluation of benefits according to the methodology shown in Figure 8.

6.2 VALIDATION OF IMPACTS AND CONTRIBUTION RATIO'S

To ensure objectiveness and credibility, each of the impacts identified in Section 4 were validated through formal interviews with acknowledged experts and key role players in the South African pavement design and construction industry during the period when the HVS investigations on G1 materials were being assimilated into the industry.

Details of these interviews are presented in Appendix D. In each interview, respondents were asked to comment on each of the identified impacts, as presented in Section 4. Respondents were also asked to comment on the assigned contribution ratio (i.e. the approximate percentage contribution of HVS investigations, specifically, to each impact).

In the following paragraphs, then, the economic returns resulting from the three main benefits identified in Section 4.5 are evaluated. Each of the benefits is evaluated in a separate subsection, and care is taken to explicitly state all assumptions and the basis thereof. Supporting data and calculations are provided in the Appendices.

6.3 BENEFIT 1: INCREASED USE OF G1 BASE PAVEMENTS FOR HIGHER DESIGN CLASSES AND WET REGIONS

This benefit is related to the increased use of G1 base pavements for the higher design classes (particularly, but not exclusively, the 12 to 50 MISA design class) and in wet regions of South Africa. Detailed background to this benefit is provided under Sections 2, 3 and 4. The calculation of economic returns is presented in Figure 9, for different road categories. A summary of savings is shown in Table 7. Key assumptions and supporting notes are provided below.

Supporting Notes and Assumptions for Figure 9:

- A key element associated with the economic evaluation of this benefit is the life cycle cost evaluation for the different design options. This aspect is discussed in detail in Appendix B. In particular, the life cycle costs associated with the different design alternatives are those of the re-evaluation of earlier studies, as presented in Appendix B, and for a nominal discount rate of 8 per cent.
- All savings shown in Figure 9 are in 1985 terms. In the summary below, these savings are discounted to 1978 terms to enable the calculation of a benefit cost ratio using the costs presented in Section 5 (presented in 1978 terms).
- Care was taken to acknowledge that the use of Crushed Stone base pavements was already established at the time when HVS investigation results became available. Thus a significant probability was assigned to the construction of G1 base pavements, even had the findings of HVS investigations not been available. This probability was then increased for the scenario where HVS findings were available, to reflect the impact of the HVS investigations. *The calculation in Figure 9 thus reflects an increased acceptance of G1 base pavements for the road classes shown*, and it is believed that this increased acceptance is to a large extent owed to the HVS investigations on G1 base pavements, as validated by the interviews presented in Appendix D.
- The period for which this benefit is calculated is between 1980 and 1990. Essentially, this means that, had the HVS investigations not been performed, the road building industry would have realized this benefit only after 1990, and this would most likely have happened through long term monitoring of the performance of constructed G1 base pavements.
- The scaling of costs for Gautrans and SANRAL is based on the total lane-km length of G1 base pavement constructed by Gautrans and SANRAL in the period 1980 to 1990. Thus the length of road shown under Lane-Km in the cost scaling section is the approximate lane km of G1 base pavement built between 1980 and 1990 by the relevant agency. Details of the calculations for these Km-lengths of road are presented in Appendix C.

Roads with > 30 MISA Design Traffic						
Situation	Design Alternatives	Probability of Implementation	Life Cycle Cost/Sq.m	Adjusted Cost/Sq.m	Total Adjusted Cost/Sq.m	
Without HVS Test Programme	Concrete	0.4	R 31.00	R 12.40		
	Asphalt	0.3	R 31.45	R 9.43	R	28.21
	G1Base	0.3	R 21.27	R 6.38		
With HVS Test Programme	Concrete	0.3	R 31.00	R 9.30		
	Asphalt	0.2	R 31.45	R 6.29	R	26.22
	G1Base	0.5	R 21.27	R 10.63		
Savings	R 1.99 per square metre					
	R 7.77 per metre of 3.9 m wide lane					
	R 7,767.60 per Km of 3.9 m wide lane					
Cost Scaling:	Owner	Lane-Km	Saving			
	GAUTRANS	3	R 23,303			
	SANRAL	122	R 947,647			
Total Aggregated Saving Estimate =			R 970,950			

Roads With 12 to 30 MISA Design Traffic						
Situation	Design Alternatives	Probability of Implementation	Life Cycle Cost/Sq.m	Adjusted Cost/Sq.m	Total Adjusted Cost/Sq.m	
Without HVS Test Programme	Concrete	0.25	R 31.00	R 7.75		
	Asphalt	0.25	R 31.45	R 7.86	R	26.24
	G1Base	0.5	R 21.27	R 10.63		
With HVS Test Programme	Concrete	0.1	R 31.00	R 3.10		
	Asphalt	0.1	R 31.45	R 3.14	R	23.26
	G1Base	0.8	R 21.27	R 17.01		
Savings	R 2.99 per square metre					
	R 11.65 per metre of 3.9 m wide lane					
	R 11,651.39 per Km of 3.9 m wide lane					
Cost Scaling:	Owner	Lane-Km	Saving			
	GAUTRANS	102	R 1,188,442			
	SANRAL	29	R 337,890			
Total Aggregated Saving Estimate =			R 1,526,333			

Roads with 8 to 12 MISA Design Traffic						
Situation	Design Alternatives	Probability of Implementation	Life Cycle Cost/Sq.m	Adjusted Cost/Sq.m	Total Adjusted Cost/Sq.m	
Without HVS Test Programme	Concrete	0	R 31.00	R -		
	Asphalt	0.3	R 31.45	R 9.43	R	24.32
	G1Base	0.7	R 21.27	R 14.89		
With HVS Test Programme	Concrete	0	R 31.00	R -		
	Asphalt	0.15	R 31.45	R 4.72	R	22.79
	G1Base	0.85	R 21.27	R 18.08		
Savings	R 1.53 per square metre					
	R 5.96 per metre of 3.9 m wide lane					
	R 5,957.87 per Km of 3.9 m wide lane					
Cost Scaling:	Owner	Lane-Km	Saving			
	GAUTRANS	33	R 196,610			
	SANRAL	0	R 0			
Total Aggregated Saving Estimate =			R 196,610			

Figure 9: Benefit Calculation for Impact 1 (Increased Implementation of G1 Pavements)

Table 7: Savings Realized Due To Increased Application of G1 Base Pavements in Higher Design Classes and Wet Regions

Benefit To	In Terms Of	At a Discount Rate Of:		
		4%	8%	12%
Gautrans	1978 Rand	R 1,070,234	R 821,761	R 637,068
	1985 Rand	R 1,408,355	R 1,408,355	R 1,408,355
	2004 Rand	R 2,967,191	R 6,078,037	R 12,129,822
SANRAL	1978 Rand	R 976,903	R 750,099	R 581,512
	1985 Rand	R 1,285,537	R 1,285,537	R 1,285,537
	2004 Rand	R 2,708,433	R 5,547,994	R 11,072,025
Total	1978 Rand	R 2,047,136	R 1,571,860	R 1,218,580
	1985 Rand	R 2,693,892	R 2,693,892	R 2,693,892
	2004 Rand	R 5,675,624	R 11,626,032	R 23,201,848

Note: Savings were calculated in terms of 1985 Rand, and thus the discount rate does not affect the savings in 1985 terms.

The savings summarized in Table 7 represent the total saving to the Gautrans and former Department of Transport, owing to the move towards increased use of G1 base pavements, especially for higher traffic designs and for wet regions. However, as shown in Figure 7 and discussed in section 4.2, the HVS was only one contributor (albeit a significant one) towards the realization of these savings.

Based on interviews conducted with acknowledged experts in the road building industry, it is estimated that the contribution of HVS investigations to realizing this shift toward G1 base pavements is between 50 per cent and 80 per cent (interview details can be found in Appendix D). Thus for a nominal 8 per cent discount rate, the estimated contribution of HVS tests on G1 base pavements, is roughly between R 0.8 million and R 1.3 million (in terms of 1978 Rand).

The calculation of this saving is based on the assumption that at least some of the G1 base pavements built between 1980 and 1990 would have been either concrete or asphalt base pavements, was it not for the significantly increased confidence and understanding provided by the HVS investigations on G1 pavements. The calculation summarized in Figure 9 uses the probability concept to calculate an aggregated saving over the total lane-km of G1 base pavement that was constructed between 1980 and 1990.

This calculation can be validated through reference to specific roads that were initially designed as concrete or asphalt pavements, but later re-designed and built as G1 base pavements, owing in part to the impact of HVS investigations on G1 base pavements. Based on information provided by industry experts, such roads include^{Note 1} parts of National Route 1 (Specifically Warmbaths to Pietersburg) and National Route 2 (portions of South Coast and North Coast toll roads).

To put the aggregated cost savings into perspective, the case of National Route 1 between Warmbaths and Pietersburg can be considered. This section (more than 100 km of undivided 4 lane road), was initially designed in concept as a concrete road, but later redesigned and built as a G1 base pavement.

Note 1: See Appendix D, and specifically interviews with B Nothnagel, D Rossmann and G Jordaan for details.

As shown in Appendix C, the life cycle cost saving realized when a G1 base pavement is built instead of a concrete base pavement is roughly R10 per m² (1985 rand terms). Thus the cost savings realized through the construction of this section using a G1 base, was in excess of R10 million (in 1985 rand terms), even if a medium contribution ratio of 70 per cent is assumed. Thus the aggregated savings calculation shown in Figure 9 is believed to be realistic, and tends to under-estimate rather than over-estimate the savings as a result of increased use of G1 base pavements on higher road categories.

6.4 BENEFIT 2: USE OF 150 MM THICKNESS FOR G1 BASE LAYERS

This benefit is related to the conclusion that the use of a 150 mm G1 base thickness is optimal for G1 bases. This conclusion stems partly from investigations by Maree (1978) and was later validated through HVS tests and associated investigations. This conclusion firmly established the notion that a somewhat thinner Crushed Stone layer was generally preferred over a 200 mm thick layer, and signalled a move away from the philosophy that thicker pavement layers are always better. More details on this aspect are provided in Section 4. The benefit calculation is presented in Figure 10, for different road categories. The savings realized through this benefit are summarized in Table 8. Key assumptions and supporting notes are provided below.

Supporting Notes and Assumptions for Figure 10:

- The material cost is based on the cost data published by Walker and Freeme (1985), and is in terms of 1985 rand. The cost is based on a rate of R 4.20 per m² for a 150 mm thick G1 base.
- The calculation reflects a broad move away from the use of thicker (i.e. greater than 150 mm) Crushed Stone bases. The calculations presume that the tendency to use a thicker (200 mm) G1 base would be more pronounced for the higher traffic class pavements.
- The calculation presumes that, owing to the dissemination of the findings of the HVS investigations on G1 base pavements, as well as of the findings of related studies, the use of 200 mm thick G1 base layers has effectively ceased.

Table 8: Savings Realized Due to Increased Use of 150 mm Thick G1 Base Layers

Benefit To	In Terms Of	At a Discount Rate Of:		
		4%	8%	12%
Gautrans	1978 Rand	R 276,333	R 212,178	R 164,490
	1985 Rand	R 363,636	R 363,636	R 363,636
	2004 Rand	R 766,126	R 1,569,344	R 3,131,910
SANRAL	1978 Rand	R 426,533	R 327,506	R 253,898
	1985 Rand	R 561,288	R 561,288	R 561,288
	2004 Rand	R 1,182,549	R 2,422,351	R 4,834,240
Total	1978 Rand	R 702,866	R 539,684	R 418,389
	1985 Rand	R 924,924	R 924,924	R 924,924
	2004 Rand	R 1,948,675	R 3,991,695	R 7,966,150

Note: Savings were calculated in terms of 1985 Rand, and thus the discount rate does not affect the savings in 1985 terms.

The savings summarized in Table 8 represent the total saving to the Gautrans and former Department of Transport, owing to the move towards 150 mm thick G1 bases, especially for higher traffic designs. However, as shown in Figure 7 and discussed in section 4.2, the HVS was only one contributor towards the realization of these savings.

Roads with > 30 MISA Design Traffic						
Situation	Design Alternatives	Probability of Implementation	Life Cycle Cost/Sq.m	Adjusted Cost/Sq.m	Total Adjusted Cost/Sq.m	
Without HVS Test Programme	200 mm	0.7	R 5.60	R 3.92		
	150 mm	0.3	R 4.20	R 1.26	R	5.18
With HVS Test Programme	200 mm	0	R 5.60	R -		
	150 mm	1	R 4.20	R 4.20	R	4.20
Savings	R	0.98 per square metre				
	R	3.82 per metre of 3.9 m wide lane				
	R	3,822.00 per Km of 3.9 m wide lane				
Cost Scaling:	Owner	Lane-Km	Saving			
	GAUTRANS	3	R 11,466			
	SANRAL	122	R 466,284			
Total Aggregated Saving Estimate =			R 477,750			

Roads With 12 to 30 MISA Design Traffic						
Situation	Design Alternatives	Probability of Implementation	Life Cycle Cost/Sq.m	Adjusted Cost/Sq.m	Total Adjusted Cost/Sq.m	
Without HVS Test Programme	200 mm	0.6	R 5.60	R 3.36		
	150 mm	0.4	R 4.20	R 1.68	R	5.04
With HVS Test Programme	200 mm	0	R 5.60	R -		
	150 mm	1	R 4.20	R 4.20	R	4.20
Savings	R	0.84 per square metre				
	R	3.28 per metre of 3.9 m wide lane				
	R	3,276.00 per Km of 3.9 m wide lane				
Cost Scaling:	Owner	Lane-Km	Saving			
	GAUTRANS	102	R 334,152			
	SANRAL	29	R 95,004			
Total Aggregated Saving Estimate =			R 429,156			

Roads with 3 to 12 MISA Design Traffic						
Situation	Design Alternatives	Probability of Implementation	Life Cycle Cost/Sq.m	Adjusted Cost/Sq.m	Total Adjusted Cost/Sq.m	
Without HVS Test Programme	200 mm	0.1	R 5.60	R 0.56		
	150 mm	0.9	R 4.20	R 3.78	R	4.34
With HVS Test Programme	200 mm	0	R 5.60	R -		
	150 mm	1	R 4.20	R 4.20	R	4.20
Savings	R	0.14 per square metre				
	R	0.55 per metre of 3.9 m wide lane				
	R	546.00 per Km of 3.9 m wide lane				
Cost Scaling:	Owner	Lane-Km	Saving			
	GAUTRANS	33	R 18,018			
	SANRAL	0	R 0			
Total Aggregated Saving Estimate =			R 18,018			

Figure 10: Benefit Calculation for Impact 2 (Use of 150 mm G1 base layer considered optimal)

Based on interviews conducted with acknowledged experts in the road building industry, it is estimated that the contribution of the HVS to realizing the savings shown in Table 8, is between 20 and 30 per cent (interview details can be found in Appendix D).

The relatively low contribution is related to the fact that much of the analytical work that underlies the move toward thinner G1 base layers was performed before HVS investigations started. Based on interviews conducted with industry experts, the HVS investigations served to confirm the analytical predictions and also firmly established the consideration of the "pavement as a system" that underlies this benefit.

Thus for a nominal 8 per cent discount rate, the estimated savings due to this benefit, and realized through the HVS tests on G1 base pavements, is roughly between R 0.8 million and R 1.2 million (in 2004 Rand terms).

6.5 BENEFIT 3: IMPROVED MAINTENANCE AND CONSTRUCTION PRACTICES

This benefit is related to the impact that the HVS investigations had on improved construction practices, better material specifications and the recognition of the importance of timely maintenance on pavements with Crushed Stone base layers. The background to these aspects is discussed in detail in Sections 3 and 4. To evaluate the economic benefits for these aspects, a life cycle cost calculation was performed for three different performance scenarios. These scenarios are:

Scenario 1: Typical G1 Base Pavement Performance

This scenario is considered to be the reference case scenario, and is based on the typical G1 base pavement performance as documented in Appendix B.

Scenario 2: Delayed Maintenance Causing Earlier Rehabilitation

This scenario represents a case where the maintenance of an impervious surfacing is delayed, with the result that the unbound base rapidly deteriorates when water enters into the layer. The result is earlier structural rehabilitation.

Scenario 3: Poor Compaction and Material Specifications during Construction

This scenario represents a case where the material used during construction is not of the quality required for G1 materials. More importantly, it assumes a case where the base is not properly compacted. The assumed consequence is early structural rehabilitation owing to deformation in the base and disintegration of the surfacing.

The calculation of the life cycle cost for the three scenarios is presented in Appendix E. The benefit calculation presumes that, partly as a result of HVS investigations and dissemination of findings to the industry, the incidence of Scenarios 2 and 3 decreased somewhat, and the incidence of Scenario 1 increased somewhat.

The calculation of the economic benefit is presented in Figure 11. The savings realized through this benefit are summarized in Table 9. Key assumptions and supporting notes are provided below.

Roads with > 3 MISA Design Traffic						
Situation	Performance Alternatives	Probability of Realizing	Life Cycle Cost	Adjusted Cost	Adjusted Cost	Total Adjusted Cost
Without HVS Test Programme	Typical	0.6	R 18.97	R 11.38		
	Delayed Maintenance	0.3	R 20.91	R 6.27	R	20.34
	Poor Construction	0.1	R 26.88	R 2.69		
With HVS Test Programme	Typical	0.8	R 18.97	R 15.18		
	Delayed Maintenance	0.15	R 20.91	R 3.14	R	19.66
	Poor Construction	0.05	R 26.88	R 1.34		
Savings	R	0.69	per square metre			
	R	2.67	per metre of 3.9 m wide lane			
	R	2,674.18	per Km of 3.9 m wide lane			
Cost Scaling:	Owner	Km	Saving			
	GAUTRANS	301	R 804,928			
	SANRAL	1077	R 2,880,090			
Total Aggregated Saving Estimate =			R 3,685,018			

Figure 11: Benefit Calculation for Impact 3 (Improved Maintenance and Construction Practices)

Supporting Notes and Assumptions for Figure 11:

- The assumed probabilities of each scenario realizing (column 3 in Figure 11) reflect a general improvement in the life cycle design approach for Crushed Stone base pavements. In particular, it assumes that the incidence of delayed maintenance and of poor construction (owing mostly to poor compaction and inappropriate specifications), decreased from 1980 to 1990. It is further assumed that the HVS investigations and the dissemination of findings significantly contributed towards the decreased incidence of delayed maintenance and poor construction.
- The calculation of the life cycle cost for the three scenarios is presented in Appendix E. In this calculation, material cost was based on the cost data published by Walker and Freeme (1985), and the savings shown in Figure 11 is thus in terms of 1985 rand.
- The life cycle cost shown in Figure 11 is per square metre, and is based on a nominal discount rate of 8 per cent, over the 25 year design period considered for the three scenarios.
- The lane-km of road used to scale the cost per square metre to an overall saving, is based on the approximate lane-km of road, owned by Gautrans and SANRAL, with G1 base layers and traffic loading greater than 3 MISA over a 25 year design period. Details of the calculation of the total lane-km are presented in Appendix C.
- The lane-km of road used to scale the cost per square metre to an overall saving, takes into account only those G1 base pavements constructed between 1980 and 1990. Thus, the calculation shown in Figure 11 essentially considers the benefit to be relevant only for a period of 10 years.

Table 9: Savings Realized Due to Improved Maintenance and Construction Practices

Benefit To	In Terms Of	At a Discount Rate Of:		
		4%	8%	12%
Gautrans	1978 Rand	R 611,679	R 469,668	R 364,108
	1985 Rand	R 804,928	R 804,928	R 804,928
	2004 Rand	R 1,695,861	R 3,473,828	R 6,932,651
SANRAL	1978 Rand	R 2,188,632	R 1,680,505	R 1,302,807
	1985 Rand	R 2,880,090	R 2,880,090	R 2,880,090
	2004 Rand	R 6,067,916	R 12,429,609	R 24,805,531
Total	1978 Rand	R 2,800,311	R 2,150,173	R 1,666,915
	1985 Rand	R 3,685,018	R 3,685,018	R 3,685,018
	2004 Rand	R 7,763,777	R 15,903,436	R 31,738,182

Note: Savings were calculated in terms of 1985 Rand, and thus the discount rate does not affect the savings in 1985 terms.

The savings summarized in Table 9 represent the total saving to the Gautrans and former Department of Transport owing to improved maintenance, construction practices and material specifications for G1 base pavements. However, as shown in Figure 7 and discussed in section 4.2, the HVS was only one contributor towards the realization of these savings.

Based on interviews conducted with acknowledged experts in the road building industry, it is estimated that the contribution of the HVS to realizing this shift toward improved maintenance and construction practices is between 30 and 60 per cent (interview details can be found in Appendix D). Thus for a nominal 8 per cent discount rate, the estimated contribution of HVS tests on G1 base pavements to this benefit is approximately between R 5 million and R 9 million (in terms of 2004 Rand).

6.6 SUMMARY OF ECONOMIC BENEFITS

A summary of the economic benefits derived from the HVS investigations on G1 base pavements is shown in Figure 12 to 15. Figure 12 includes a summary for each of the contributing agencies and for different contribution ratios, while Figures 13 to 15 shows the expected range of benefit cost ratios for all benefits combined. In all cases, the benefits are shown for a low and high contribution ratio, since this element is a highly subjective aspect that impacts directly on the cost calculation.

It is thus left to the reader to focus on a contribution ratio that she or he feels most comfortable with. It should, however, be noted that the range of contribution ratios used in Figure 12 were validated by acknowledged experts in South African road design and construction, and can therefore be regarded as being fairly representative of the broader industry opinion.

Benefit Summary for Gautrans Investment in HVS Investigations on G1 Base Pavements									
Benefit	Lower Contribution Ratio					Higher Contribution Ratio			
	Contribution Ratio	Discount Rate of			Contribution Ratio	Discount Rate of			
		4%	8%	12%		4%	8%	12%	
Increased use of G1 Base Pavements	50%	R 535,117	R 410,881	R 318,534	80%	R 856,187	R 657,409	R 509,654	
Increased use of 150 mm Thick G1 Layers	20%	R 55,267	R 42,436	R 32,898	30%	R 82,900	R 63,653	R 49,347	
Improved Maintenance and Construction Practices	30%	R 183,504	R 140,900	R 109,233	60%	R 367,007	R 281,801	R 218,465	
Total Benefit (in 1978 Rand):	N/A	R 773,887	R 594,217	R 460,665	N/A	R 1,306,094	R 1,002,863	R 777,467	
Total Cost (in 1978 Rand):	N/A	R 358,261	R 340,669	R 324,813	N/A	R 358,261	R 340,669	R 324,813	
Benefit: Cost Ratio	N/A	2.2	1.7	1.4	N/A	3.6	2.9	2.4	
Total Benefit (in 2004 Rand):	N/A	R 2,145,579	R 4,395,036	R 8,771,091	N/A	R 3,621,107	R 7,417,530	R 14,803,024	

Benefit Summary for SANRAL Investment in HVS Investigations on G1 Base Pavements									
Benefit	Lower Contribution Ratio					Higher Contribution Ratio			
	Contribution Ratio	Discount Rate of			Contribution Ratio	Discount Rate of			
		4%	8%	12%		4%	8%	12%	
Increased use of G1 Base Pavements	50%	R 488,451	R 375,049	R 290,756	80%	R 781,522	R 600,079	R 465,209	
Increased use of 150 mm Thick G1 Layers	20%	R 85,307	R 65,501	R 50,780	30%	R 127,960	R 98,252	R 76,169	
Improved Maintenance and Construction Practices	30%	R 656,590	R 504,152	R 390,842	60%	R 1,313,179	R 1,008,303	R 781,684	
Total Benefit (in 1978 Rand):	N/A	R 1,230,347	R 944,702	R 732,378	N/A	R 2,222,661	R 1,706,634	R 1,323,063	
Total Cost (in 1978 Rand):	N/A	R 218,277	R 194,911	R 174,765	N/A	R 218,277	R 194,911	R 174,765	
Benefit: Cost Ratio	N/A	5.6	4.8	4.2	N/A	10.2	8.8	7.6	
Total Benefit (in 2004 Rand):	N/A	R 3,411,101	R 6,987,351	R 13,944,522	N/A	R 6,162,261	R 12,622,867	R 25,191,213	

Benefit Summary for Combined Gautrans and SANRAL Investment in HVS Investigations on G1 Base Pavements									
Benefit	Lower Contribution Ratio					Higher Contribution Ratio			
	Contribution Ratio	Discount Rate of			Contribution Ratio	Discount Rate of			
		4%	8%	12%		4%	8%	12%	
Increased use of G1 Base Pavements	50%	R 1,023,568	R 785,930	R 609,290	80%	R 1,637,709	R 1,257,488	R 974,864	
Increased use of 150 mm Thick G1 Layers	20%	R 140,573	R 107,937	R 83,678	30%	R 210,860	R 161,905	R 125,517	
Improved Maintenance and Construction Practices	30%	R 840,093	R 645,052	R 500,075	60%	R 1,680,187	R 1,290,104	R 1,000,149	
Total Benefit (in 1978 Rand):	N/A	R 2,004,235	R 1,538,919	R 1,193,042	N/A	R 3,528,755	R 2,709,497	R 2,100,530	
Total Cost (in 1978 Rand):	N/A	R 576,538	R 535,580	R 499,578	N/A	R 576,538	R 535,580	R 499,578	
Benefit: Cost Ratio	N/A	3.5	2.9	2.4	N/A	6.1	5.1	4.2	
Total Benefit (in 2004 Rand):	N/A	R 5,556,680	R 11,382,386	R 22,715,611	N/A	R 9,783,368	R 20,040,396	R 39,994,235	

Note: Discount rate is applied in converting savings (which are in terms of 1985 Rand) to 1978 Rand and to 2004 Rand

Figure 12: Summary of Benefits Derived from HVS Investigations on G1 Base Pavements

The data presented in Figures 12 to 15 prompt the following observations and conclusions:

- The overall benefit cost ratio (i.e. for Gautrans and SANRAL) varies from 2.4 to 6.1, depending on the contribution ratio and discount rate selected. For a nominal discount rate of 8 per cent, the overall benefit cost ratio varies between 2.9 and 5.1, depending on the contribution ratio selected. This range of estimated benefit cost ratios is similar to the range of 3.8 to 4.9 reported for accelerated pavement testing performed in Australia (ARRB, 1992).
- For Gautrans, the estimated direct benefit derived between 1980 and 1990 from the HVS investigations on G1 base pavements is roughly between R 2.2 and R 14.8 million (in 2004 Rand terms). Taking into account the contribution made by Gautrans to the funding of HVS investigations on G1 pavements, this results in a benefit cost ratio of between 1.4 and 3.6, depending on the discount rate and contribution ratio selected.
- For SANRAL, the estimated direct benefit is roughly between R 3.4 and R 25.2 million (in 2004 Rand terms). This results in a benefit cost ratio of between 4.2 and 10.2. This benefit cost ratio is higher than that realized by Gautrans, mainly because of the greater scaling of benefits provided by the larger SANRAL pavement network.
- It should be noted that the totals shown in columns 3, 4 and 5 of the tables in Figure 12 represent a total which consists of the sum of all the lowest estimated contribution ratios. Thus the benefit cost ratios shown in these columns represent a highly conservative benefit estimate.

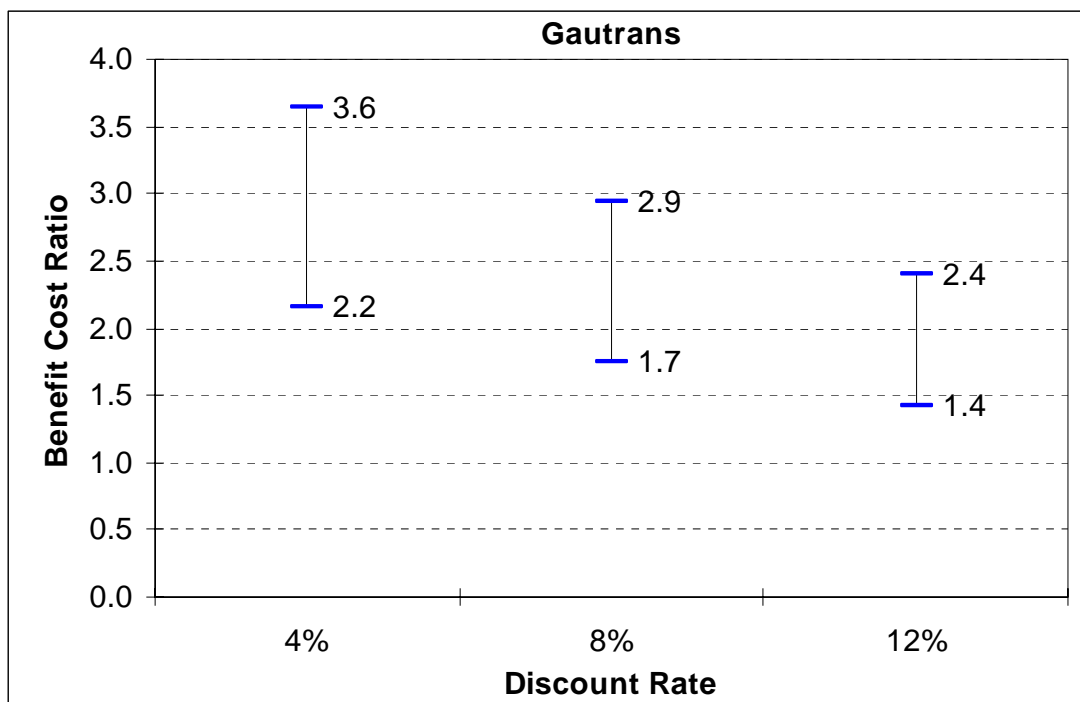


Figure 13: Summary of Likely Benefit Cost Ratio Ranges for Gautrans

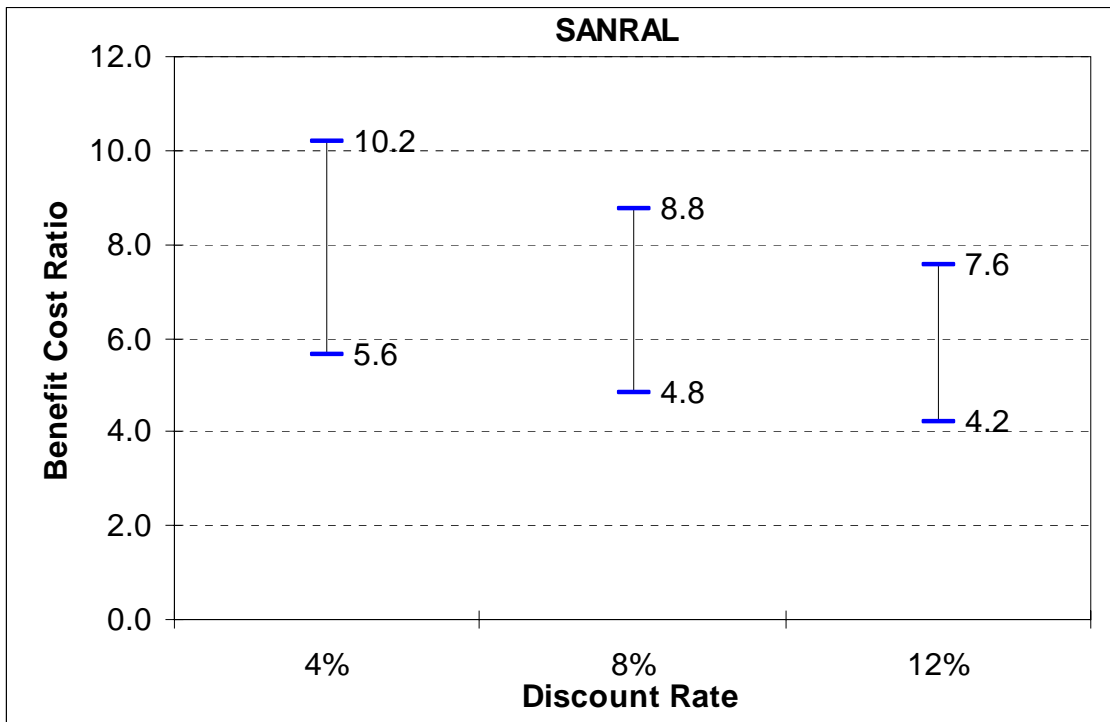


Figure 14: Summary of Likely Benefit Cost Ratio Ranges for SANRAL

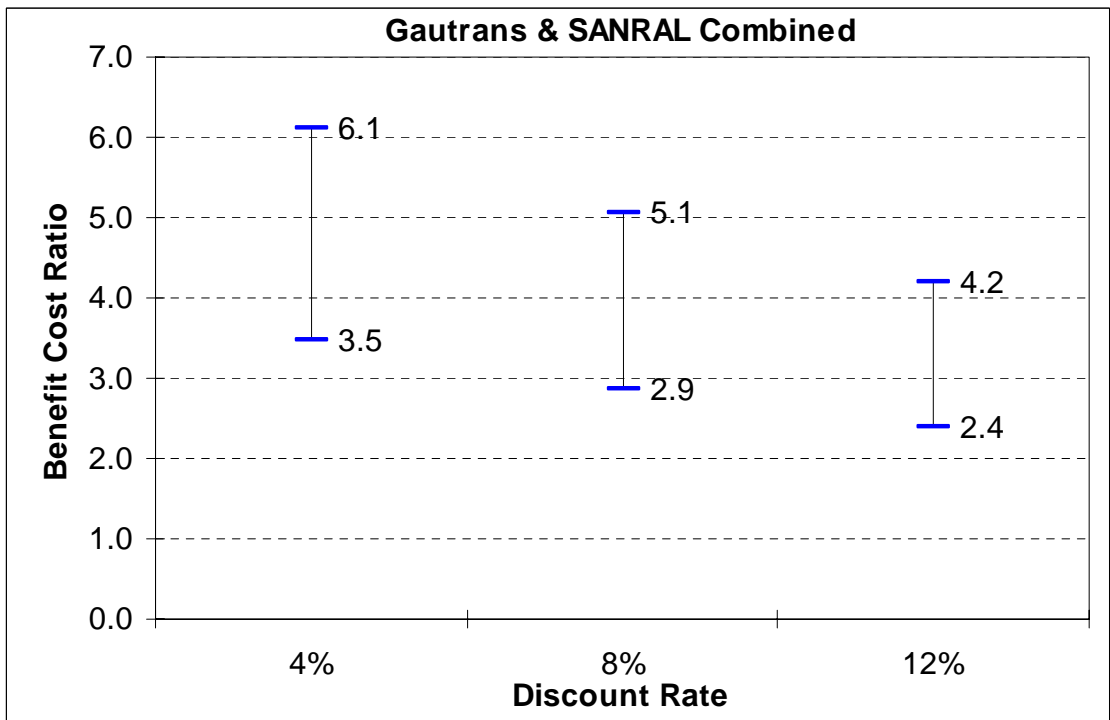


Figure 15: Summary of Likely Benefit Cost Ratio Ranges for Combined Gautrans and SANRAL Contributions

It is important to note that the benefits reported in this section, and shown in Figure 12, include only those aspects which could be converted to economic savings with reasonable confidence. There are several other benefits resulting from the HVS investigations on G1 base pavements, which cannot easily be converted to economic savings, yet are sure to impact positively on the Gautrans and SANRAL budgets and networks over the long term. These Indirect Benefits include aspects such as:

- Calibration of the South African mechanistic-empirical design method;
- Technology transfer to local and international practitioners which raised the technical competence of designers working for Gautrans and SANRAL;
- Improved understanding of the systems behaviour of granular base pavements, and particularly the interaction between the granular base and cemented subbase.
- Improved understanding of the behaviour of cemented subbase layers under loading. This led to further research into the behaviour and performance of cemented layers.

Since none of the above impacts are included in the assessment that is summarized in Figure 12, it will be appreciated that the benefits shown in Figure 12 represent a lower bound estimate of the benefits of HVS investigations on G1 base pavements. As suggested by Scott et al (2002), the simple linear benefit assessment process followed here fails to take into account the further downstream benefits and the impact of these benefits on the population at large. This means that the benefit assessment documented in this section probably greatly underestimates the true benefit stemming from the HVS investigations on G1 base pavements.

7 SUMMARY AND CONCLUSIONS

This report describes the assessment of the economic benefits stemming from HVS investigations that resulted in the development of a technology for the design and construction of pavements with high quality Crushed Stone base layers. This high quality Crushed Stone, known as G1 material in South Africa, provided a viable alternative to the thicker and more expensive pavements that were typically considered for heavily trafficked roads at the time.

Historical Background

The background to the development of G1 technology is described and the key findings of the investigations (already presented in numerous reports and international publications) are summarized and discussed. Key elements of this discussion include:

- The development of the technology for the design and construction of G1 base pavements was an extended process which was partly initiated by the former Transvaal Roads Department (TRD).
- Before the HVS investigations on G1 base pavements were conducted (between 1978 and 1982), there was considerable controversy over the structural capacity boundaries within which G1 base pavements could be expected to perform well. At the time there was doubt whether G1 base pavements could be used for the higher traffic loading applications (specifically, but not exclusively, the 12 to 50 MISA traffic category).
- The development of HVS technology was classified into two phases. These were: (i) a basic technology development phases from the early 1960's to roughly 1978, and (ii) a validation and refinement phase (1978 to 1985), in which the HVS played a pivotal role.
- There were several contributors to the successful implementation of G1 technology. The HVS development programme was one of these contributors, and played a pivotal role in validating the earlier analytical work of Maree (1978) and others. It also provided an organized structure to the documenting and validation of the performance of G1 base pavements.

Technical Impacts and Benefits

The key impacts of HVS investigations on G1 base pavements were identified as:

- The suitability for G1 base pavements for the 12 to 50 MISA design class was clearly proven;
- The feasibility of G1 base pavements in wet regions was proven (provided an impervious surfacing could be maintained);
- It was found that the damage exponent (or n-value) of pavements with a G1 base over a thick cemented subbase was close to 3, and not 4.2, as was commonly assumed;

- It was proven that a 150 mm thick G1 layer is optimal for G1 base layers;
- The difference between the high quality G1, and lower quality G2 material was clearly shown;

Since the HVS investigations was only one of the contributors to the successful implementation of G1 technology, any evaluation of economic benefits should take into account the relative contribution of other role players. For each of the identified impacts, a relative contribution percentage was therefore assigned and validated through interviews with acknowledged industry experts.

It was noted that the HVS investigations also had other impacts, such as those relating to Science and Technology development, but that these cannot be readily evaluated in economic terms.

Economic Benefits

After consideration of the identified impacts, and specifically of the data and assumptions needed to convert the impacts to economic benefits, it was decided to combine the identified impacts into the following three main benefits:

Benefit 1: Increased use of G1 Base Pavements for higher design classes and wet regions

Benefit 2: Use of 150 mm maximum thickness for G1 base layers

Benefit 3: Improved maintenance and construction practices

The savings derived from these three benefits were assessed in detail. In essence, this assessment used a probabilistic approach to aggregate the likely unit savings that typically resulted from the above three benefits. The overall savings were then calculated for the Gautrans and SANRAL networks, by using the unit cost savings, which was scaled to an absolute savings value using the total lane-km of G1 base pavements constructed by Gautrans and SANRAL in the period between 1980 and 1990. The assessment of economic benefits showed the following:

- The overall benefit cost ratio (i.e. for Gautrans and SANRAL) varies from 2.4 to 6.1, depending on the contribution ratio and discount rate selected. For a nominal discount rate of 8 per cent, the overall benefit cost ratio varies between 2.9 and 5.1, depending on the contribution ratio selected. This range of estimated benefit cost ratios is similar to the range of 3.8 to 4.9 reported for accelerated pavement testing performed in Australia (ARRB, 1992).
- For Gautrans, the estimated direct benefit derived between 1980 and 1990 from the HVS investigations on G1 base pavements is roughly between R 2.2 and R 14.8 million (in 2004 Rand terms). Taking into account the contribution made by Gautrans to the funding of HVS investigations on G1 pavements, this results in a benefit cost ratio of between 1.4 and 3.6, depending on the discount rate and contribution ratio selected.

- For SANRAL, the estimated direct benefit is roughly between R 3.4 and R 25.2 million (in 2004 Rand terms). This results in a benefit cost ratio of between 4.2 and 10.2. This benefit cost ratio is higher than that realized by Gautrans, mainly because of the greater scaling of benefits provided by the larger SANRAL pavement network.
- It should be noted that the lower bound of these benefit cost ratios represent a total which consists of the sum of all the lowest estimated contribution ratio's. Thus the lower limit of the above noted benefit cost ratios represent a highly conservative estimate.

It is important to note that the benefits that were evaluated include only those aspects which could be converted to economic savings with reasonable confidence and assumptions. There are several other benefits resulting from the HVS investigations on G1 base pavements, which cannot easily be converted to economic savings, yet are sure to impact positively on the Gautrans and SANRAL budgets and networks over the long term. These benefits include aspects such as:

- Calibration of the South African mechanistic design method;
- Technology transfer to local and international practitioners which raised the technical competence of designers working for Gautrans and SANRAL;
- Improved understanding of the systems behaviour of granular base pavements, and particularly the interaction between the granular base and cemented subbase.
- Improved understanding of the behaviour of cemented subbase layers under loading. This led to further research into the behaviour and performance of cementitious pavement layers.

Since none of the above impacts are included in the assessment of economic benefits, it will be appreciated that the above noted benefit cost ratios represent a lower bound estimate of the benefits of HVS investigations on G1 base pavements. As suggested by Scott et al (2002), the simple linear benefit assessment process that was followed in this study fails to take into account the further downstream benefits and the impact of these benefits on the population at large. This means that the benefit assessment documented in this report probably greatly underestimates the true benefit stemming from the HVS investigations on G1 base pavements.

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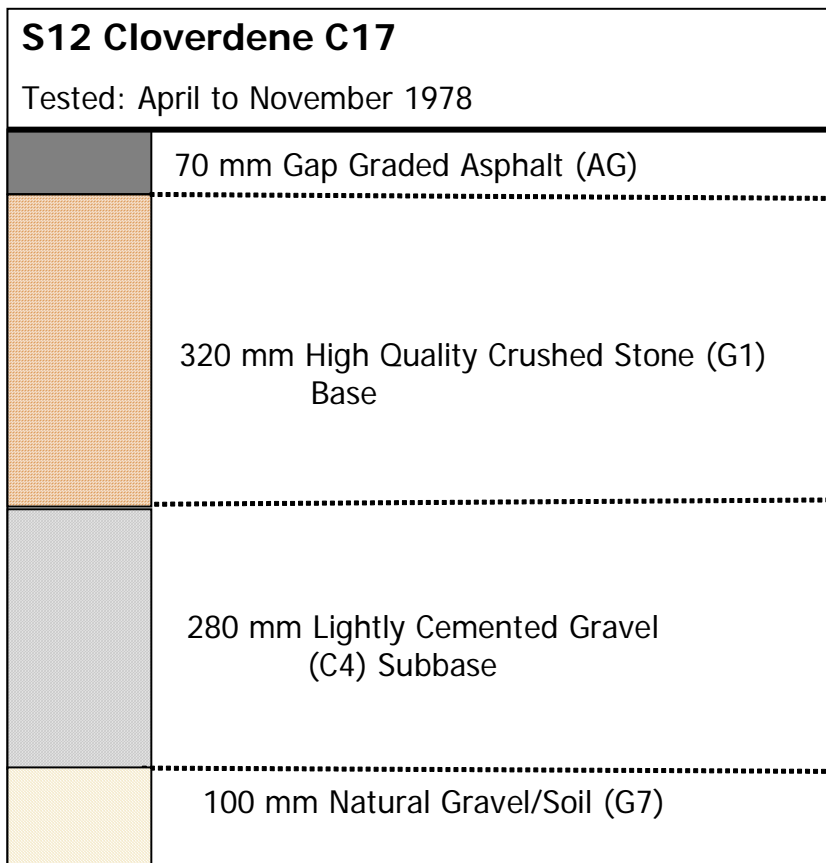
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APPENDIX A

SUMMARY OF HVS TESTS ON G1 BASE PAVEMENTS



Test Summary (after Kleyn et al, 1997)

This section formed part of a larger experimental layout and focussed on “crusher run” base layers. The overall objective of this test was to determine whether Crushed Stone base pavements are suitable for accommodating heavy traffic and also to determine the “critical” thickness for gap-graded asphalt surfacing for such pavements.

This test was conducted in the aftermath of the failures on road S12, which tied up the Transvaal provincial government in a court action and cast doubts among pavement engineers about the ability of crusher run base pavements to accommodate heavy traffic.

The test applied 2 million repetitions of a 65 kN wheel load (520 kPa tyre pressure) which is equivalent to roughly 14 million Equivalent Standard Axles (MESA) (assuming a damage exponent of 4.0).

Key observations and conclusions:

- The high quality Transvaal crusher run base (now generally referred to as “Crushed Stone” base), supported by a cemented subbase, showed less than 3 mm permanent deformation after 13.9 MESA.
- The pavement was not sensitive to wheel load and showed stress stiffening behaviour under increased wheel loading.
- The open-graded surfacing layer was stable and confirmed the load carrying capability of this type of asphalt.

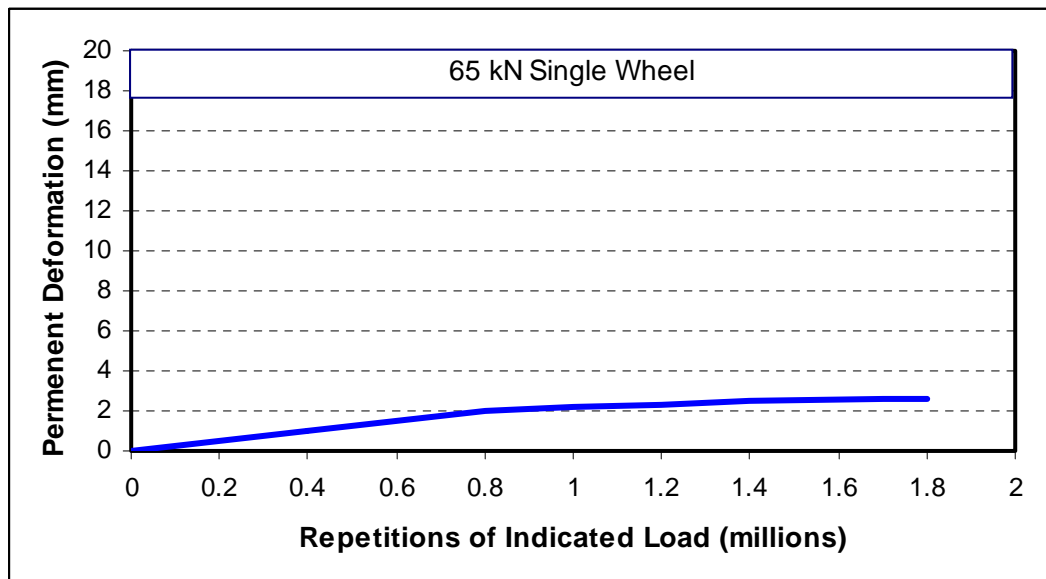


Figure A1. Development of permanent deformation on Road S12, Cloverdene

Road 1955, Ogies K17		Road 1955, Ogies K11	
Tested: November 1978 to April 1979		Tested: May to July, 1979	
	35 mm Gap Graded Asphalt (AG)		35 mm Gap Graded Asphalt (AG)
	125 mm High Quality Crushed Stone (G1) Base		100 mm High Quality Crushed Stone (G1) Base
	150 mm Natural Gravel (G4) Subbase		150 mm Natural Gravel (G4) Subbase
	1000 mm Soil (G10) (imported subgrade) <i>(not drawn to scale)</i>		250 mm Gravel/Soil (G7) <i>(not drawn to scale)</i>

Test Summary (after Kleyn et al, 1997)

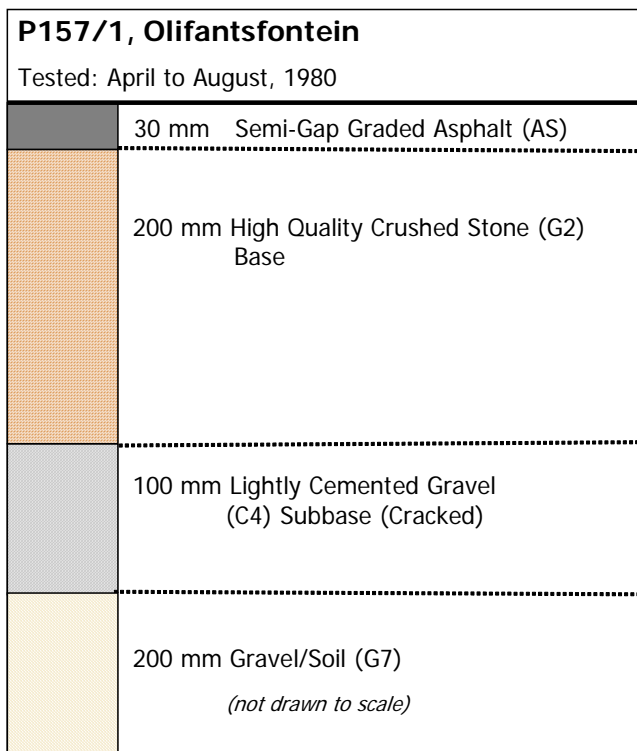
This section was close to road S12 (now N12 Section 20), at the interchange with district road 1955. This section represented a lower category road (compared to road S12) which was considered to be easier to fail under the HVS.

This section was specifically designed to have a weak subgrade consisting of a 1 metre thick clay material with a laboratory tested California Bearing Ratio (CBR) of 5 per cent and a compaction effort of 90 per cent Mod. AASHTO. The pavement also had no stabilized subbase, and as such was designed to be a light structure that would fail easily.

Test Loading on Road 1955				
Test Section	Wheel Load (kN)	Tyre Pressure (kPa)	Repetitions (millions)	MESA (assuming n= 4.0)
36	40	520	2.0	2.0
37	60	520	2.0	10.1
38	100	520	0.5	19.5

Key observations and conclusions:

- The pavement proved surprisingly resistant to HVS trafficking, and only the asphalt wearing course showed any signs of failure.
- Investigations showed that the subgrade was much stronger than anticipated, owing mostly to its field moisture content, which was lower than expected.
- Both the deformation and cracking progression at different wheel loads suggested that the damage or equivalency exponent " n " was not equal to 4.0 as was generally accepted at that time. Rather, the value of n was found to be between 2 and 3 for this specific site.



Test Summary (after Kleyn et al, 1997)

This road runs between Pretoria and Johannesburg International Airport. When HVS testing was conducted, it had carried more than 2 MESA of fairly heavy traffic. Although the pavement was performing well with little sign of undue distress, it was one of the early implementations of high quality Crushed Stone technology, with relatively little subbase support.

The test first applied a 70 kN wheel load. When no significant damage was observed after 1.5 million load applications, the load was increased to 100 kN. This load increase, together with the introduction of water, then resulted in observable damage (8 mm final deformation).

Test Loading on Road P157-1				
Test Section	Wheel Load (kN)	Tyre Pressure (kPa)	Repetitions (millions)	MESA (assuming n= 4.0)
101	70	520	1.50	14.1
	100	520	0.63	24.6

Key observations and conclusions:

- The test result increased confidence in the ability of Crushed Stone base pavements to accommodate very heavy traffic.
- The load equivalency exponent "n" again proved to be less than the generally accepted value of 4.0.
- Deflection measurements suggested that the subbase was extensively cracked. Despite this, no stabilization cracks were observed, which showed that Crushed Stone layers have good crack damping characteristics.
- The test showed that non-linear elastic models was more accurate than conventional linear elastic models in predicting failure in Crushed Stone base layers, and assisted in the development of a theory to predict failure in Crushed Stone layers.

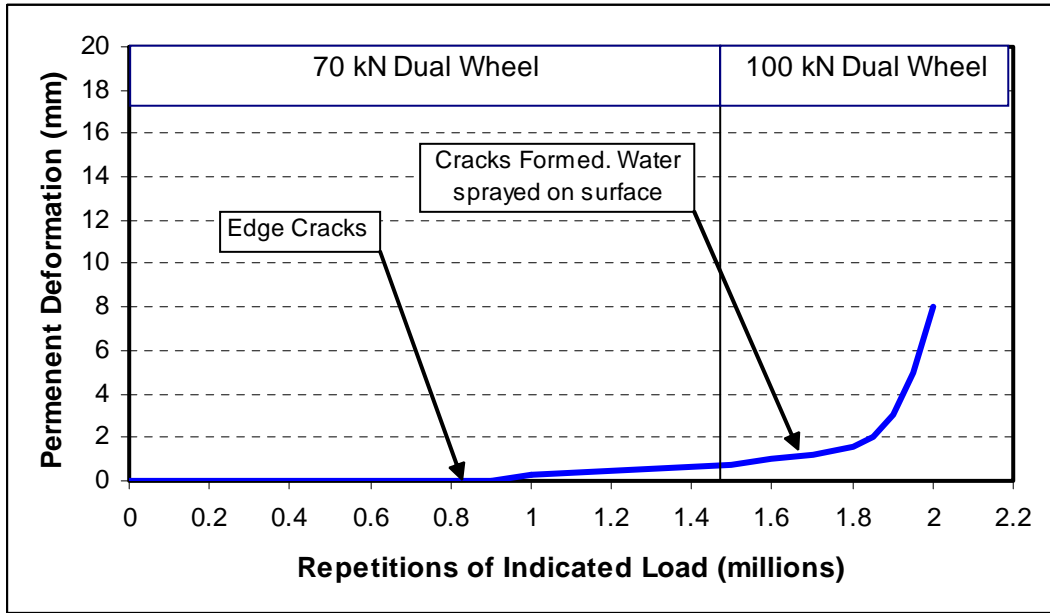


Figure A2. Development of permanent deformation on Road P157/1

P157/2, Jan Smuts	
Tested: August to December, 1980	
35 mm	Semi-Gap Graded Asphalt (AS)
140 mm	High Quality Crushed Stone (G1) Base
255 mm	Cemented Gravel (C3) Subbase (Cracked)
125 mm	Natural Gravel (G5/G6)

Test Summary (after Kleyn et al, 1997)

This section represented a subsection of road P157 which had earlier failed because of poor construction and was subsequently rebuilt to a higher standard. At the time, there was concern whether the rebuilt section was in fact an improvement on the first construction. The design and construction of this new section perhaps represented "state of the art" understanding of the behaviour and performance of high quality Crushed Stone bases at the time.

When less than 1 mm deformation was observed after some 30 MESA had been applied, water was introduced into the pavement through holes that were drilled into the pavement up to subgrade depth along the length of the test section. The introduction of water lead to a rapid increase in permanent deformation. However, the rate of deterioration fell of sharply when the applied wheel was reduced to 40 kN.

Test Loading on Road P157-2				
Test Section	Wheel Load (kN)	Tyre Pressure (kPa)	Repetitions (millions)	MESA (assuming n= 4.0)
107	70	520	0.48	4.5
	100	520	0.66	25.8
	40	520	0.29	0.3
	100	520	0.29	11.3

Key observations and conclusions:

- A Crushed Stone base pavement in which the base is of high quality, well constructed and well supported by a thick cemented layer, has a structural capacity of up to 50 MESA, provided the pavement is adequately maintained and water is kept out of the pavement structure.
- The thickness of a Crushed Stone base need not be more than 150 mm if well supported by a cemented subbase.
- A lesser quality, more open graded Crushed Stone (such as that encountered on P157-1) is more susceptible to water ingress and consequent loss in strength.
- The equivalency exponent "n" for a well designed G1 base pavement is approximately 3, and not 4 as generally accepted at the time of testing.
- For Crushed Stone base layers, there is little benefit from using a thickness of more than 150 mm. This is shown by the permanent deformation on this structure, which is slightly less than that of Road S12, which had a 320 mm thick base. A thickness of 150 mm was thus considered to be optimal for a Crushed Stone base layer on a cemented support.

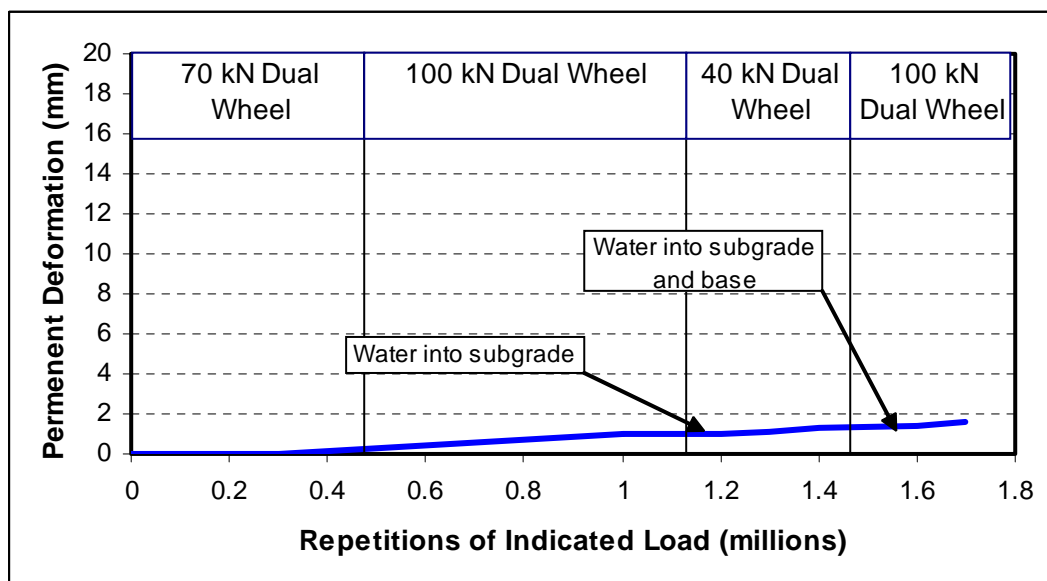
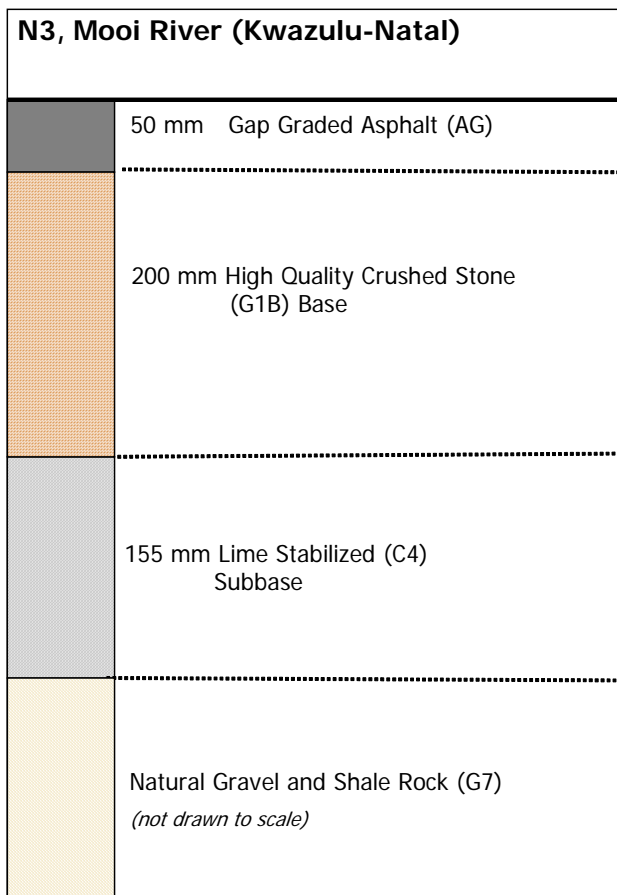


Figure A3. Development of permanent deformation on Road P157/2



Test Summary (after Maree, 1982)

During this test, the rate of deformation observed in the early stages of the test was greater than what was observed in earlier HVS tests in the Gauteng province. Most likely causes for this was the higher degree of saturation in the Crushed Stone base as well as the lower specification density (on this road, a saturation density of 50 to 85 % was obtained, instead of the normal value of less than 50).

After approximately 0.2 million applications of an 80 kN load, the rate of deformation decreased until the surfacing started to crack at 0.5 million load applications. After some rain, and an increase in wheel load, the rate of deformation again increased.

Test Loading on Road N3, Mooi River				
Test Section	Wheel Load (kN)	Tyre Pressure (kPa)	Repetitions (millions)	MESA (assuming n= 4.0)
N3 Mooi River	80	520	1.01	18.6
	90	520	0.22	6.8
	100	520	0.13	6.2

Key observations and conclusions:

- Permanent deformation of roughly 15 mm was observed after 18.6 MESA had been applied. Much of this deformation occurred after the surfacing had cracked and rain had penetrated into the surface.
- The deformation behaviour was attributed mainly to consolidation (as opposed to shear failure), which was a result of the lower density achieved during construction.

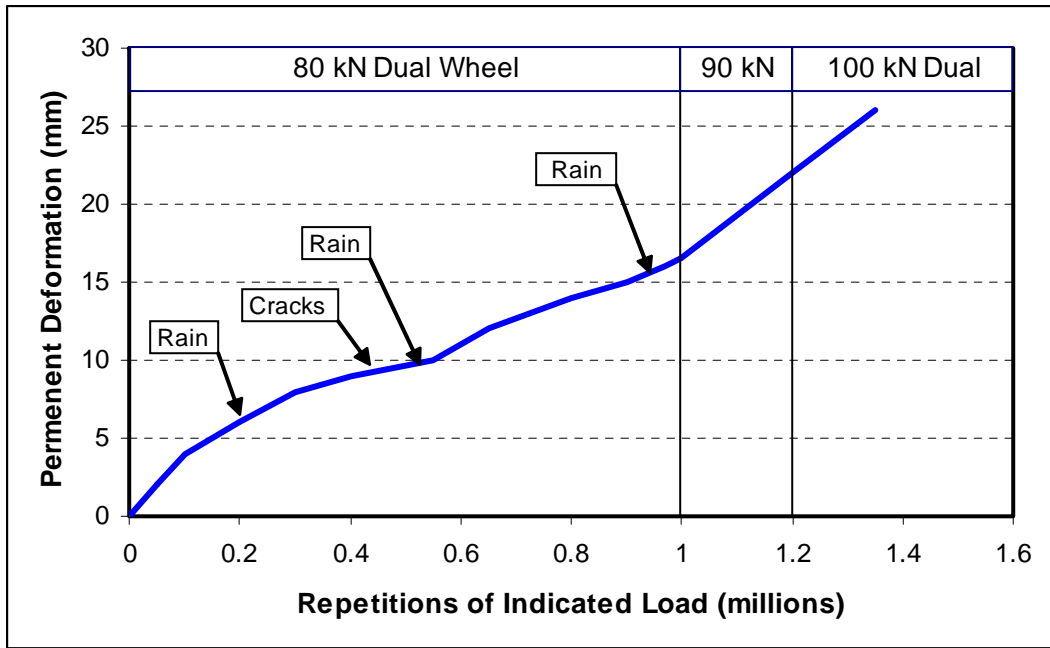
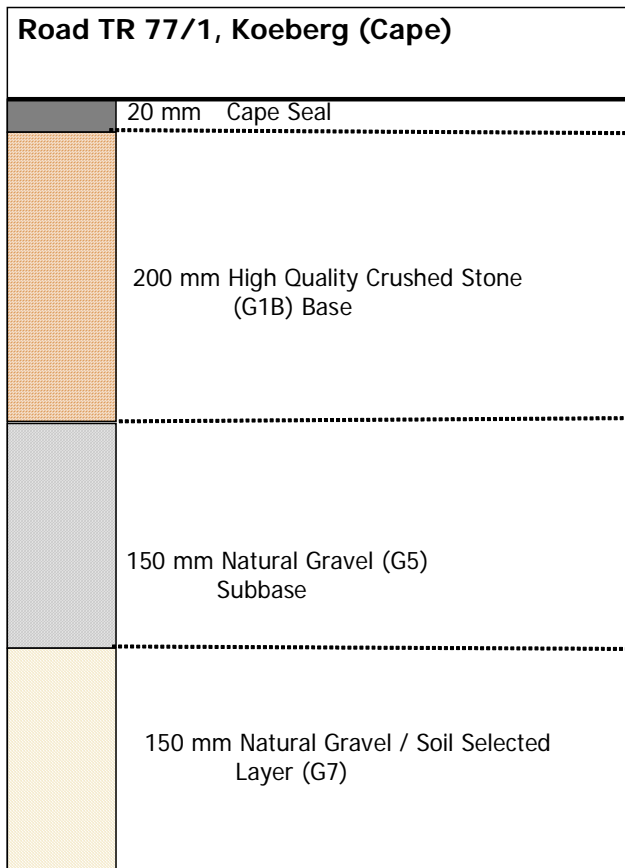


Figure A4. Development of permanent deformation on Road N3, Mooi River



Test Summary (after Maree, 1982)

Two tests were carried out on this road. The first test showed behaviour similar to that measured on N3, Mooi River. However, during the test one of the Multi-Depth Deflectometer (MDD) instrumentation holes collapsed and caused rapid ingress of water into the structure, with a consequent increase in deformation. The sensitivity of the pavement to moisture contrasts to the behaviour measured on P157/2, which showed much less sensitivity to moisture. This observation was attributed to the more open graded nature of the G1 on this structure.

In the second test on this road the base layer was quite wet from the start of the test (saturation of 50 to 80 per cent). The base was also not very dense and not well supported by a cemented subbase (it was later found that most of the deformation occurred in the subbase, and not in the base). This test showed the greatest deformation after loading and showed a significant increase in deformation after water was introduced into the structure.

Test Loading on Road GP77/1, Koeberg (Western Cape)				
Test Section	Wheel Load (kN)	Tyre Pressure (kPa)	Repetitions (millions)	MESA (assuming n= 4.0)
Test A	70	520	0.95	10.9
Test B	70	520	0.32	11.3
	100	520	0.35	12.7

Key observations and conclusions:

- Permanent deformation can form rapidly in a Crushed Stone base that is not at a high density and in which water has penetrated.

- There is a definite difference between the performance of a Crushed Stone base on an unbound subbase, compared to that of a Crushed Stone base on a cemented subbase.

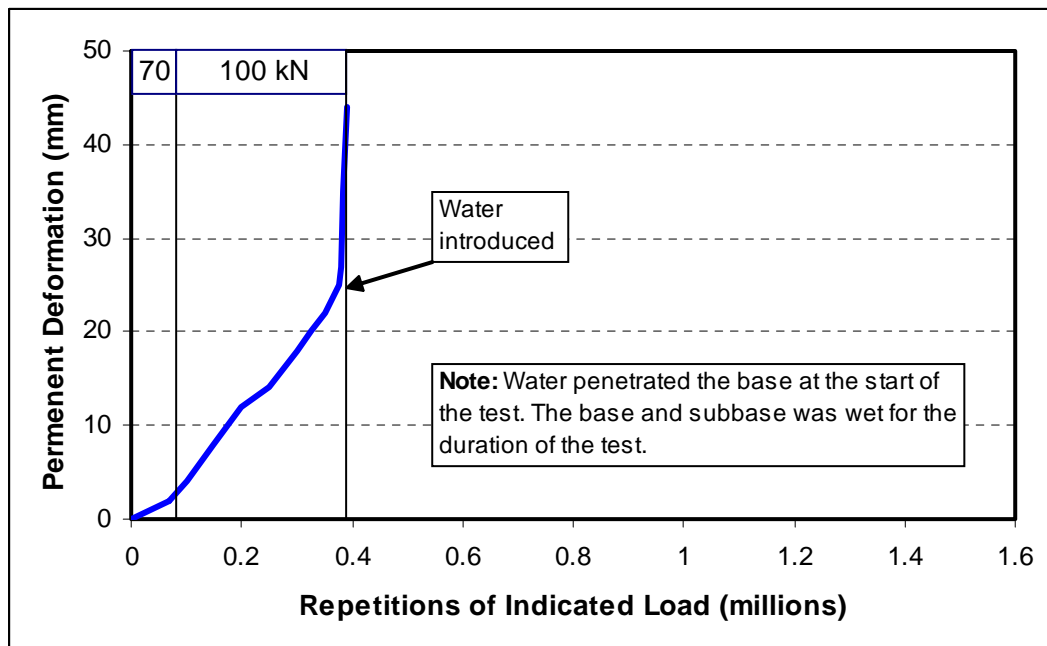


Figure A5. Development of permanent deformation on Road TR77/1, Koeberg

APPENDIX B

**LIFE CYCLE COST OF DIFFERENT DESIGN
ALTERNATIVES**

Introduction

In this appendix, the life cycle cost associated with different design alternatives - all suited to the 12 to 50 MISA design category – is presented. The alternatives and unit costs considered are those which were applicable at the time when the findings of the HVS investigations on G1 base pavements were published and being assimilated by the industry (roughly 1982 to 1985).

Study by Mitchell and Walker (1985)

The 1985 study by Mitchell and Walker (Mitchell and Walker, 1985) provides invaluable information in the determination of life cycle costs for pavements in the 12 to 50 MISA traffic class. The study by Mitchell and Walker not only establishes the feasible design alternatives, but also the material costs and basic assumptions associated with life cycle cost determination. The design alternatives typically considered for the 12 to 50 MISA design class in 1985 are summarized in Figure B1 (also in Figure 5).

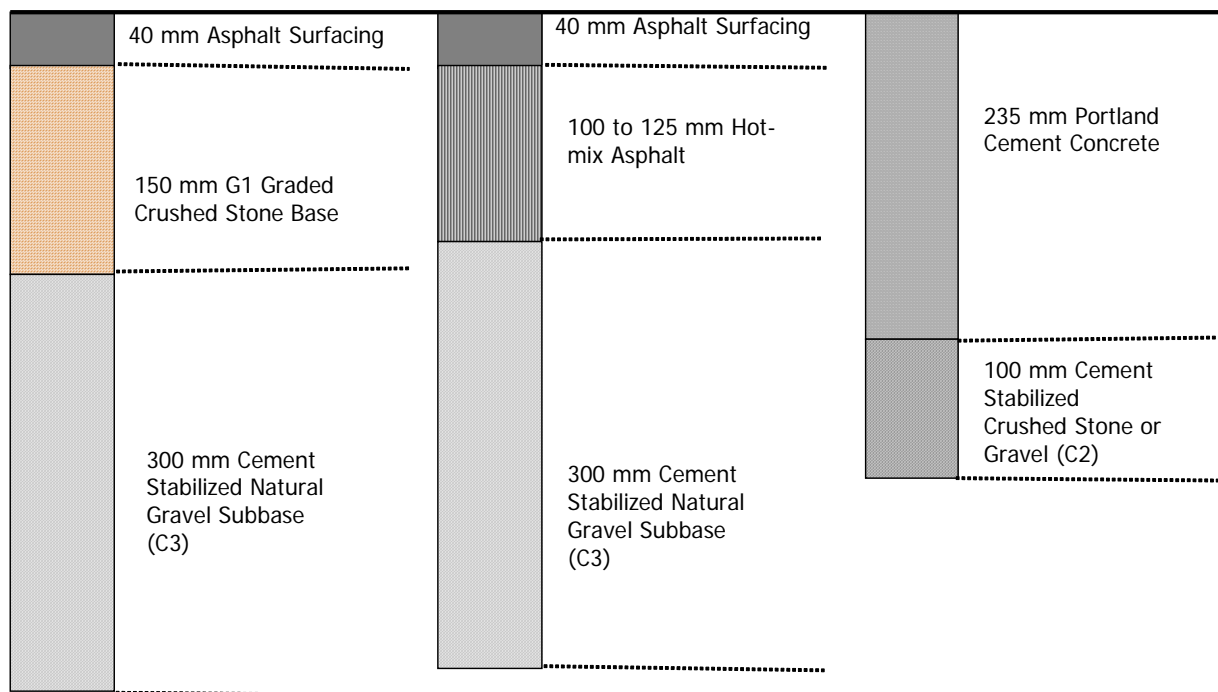


Figure B1. Designs alternatives considered in 1985 for traffic demands of 10 to 50 MISA (Mitchell and Walker, 1985).

Key assumptions associated with the life cycle cost determination are summarized below (Figure B2 shows these assumptions in a schematic format):

- For the granular (G1) base pavement, a surface treatment at 9 years was assumed, together with a 40 or 100 mm overlay at 18 years. Another surface treatment was assumed at 24 years.
- For the asphalt base pavement, a surface treatment at 9 years was assumed, together with a 40 mm overlay at 18 years. Another surface treatment was assumed at 24 years.

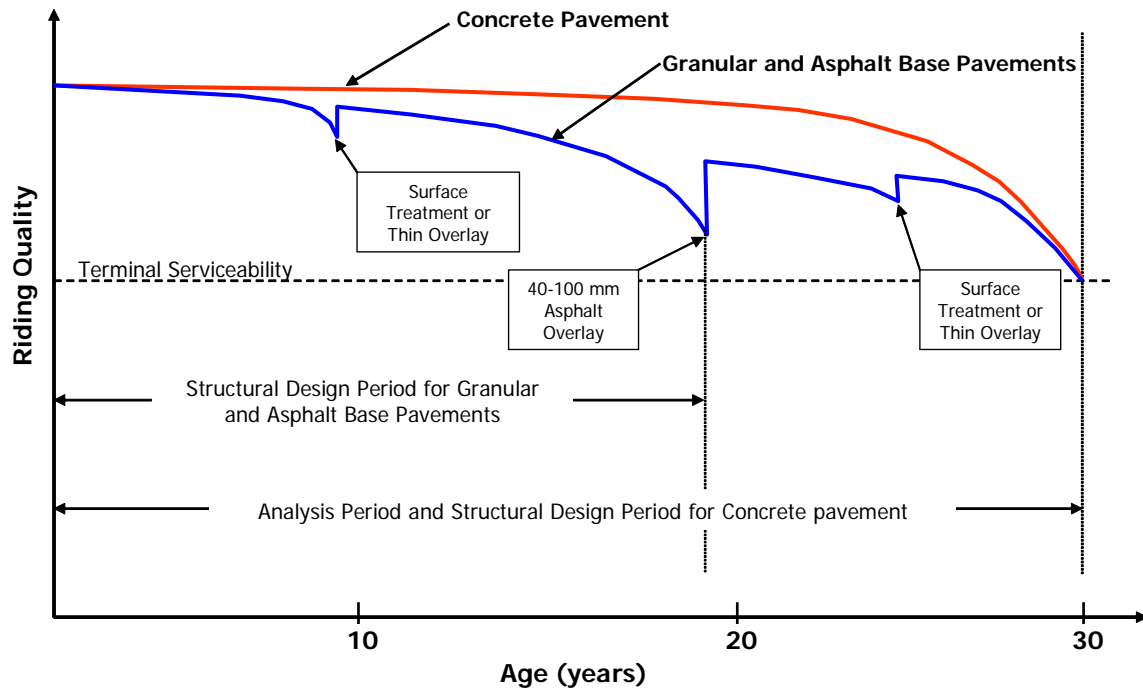


Figure B2. Assumptions related to life cycle cost determination made by Mitchell and Walker (1985).

- The structural design period of the concrete pavement was 30 years. During this period, no rehabilitation actions were assumed, and only minor maintenance at age 20 years was assumed, at a cost of R0.50 cents per square metre.
- The estimation of salvage value was based on the residual structural value approach. According to this approach, the salvage value percentage is based on the difference in the cost of (i) building a new pavement and (ii) that of restoring the deteriorated pavement by means of structural rehabilitation.
- For the concrete pavement, it was assumed that 200 mm of concrete overlay would be needed to restore the pavement to its original capacity. Compared to the cost of a new pavement, this assumption suggested a salvage value of 30 per cent.
- For the granular base pavement, it was assumed that the base and asphalt layers would need replacement after 30 years. In the calculation, it was considered that the removed asphalt and granular material would be available for recycled use in a nearby pavement (this was considered as a saving). Based on these assumptions, and compared to the cost of a new pavement, the salvage value would be 30 per cent.
- For the asphalt base pavement, it was assumed that a 100 mm overlay would be needed to restore the pavement to its original structural capacity. Compared to the cost of building a new pavement of the same capacity, the calculated salvage value was roughly 50 per cent.
- Road user delay costs (RUDC) were calculated on a weighted utility basis and determined to be 80 per cent of the present worth of maintenance costs. This figure was thus added to the calculated present worth of costs (based on initial construction and maintenance cost alone).

The unit rates used for materials and maintenance actions were based on detailed rates from (then) recent road rehabilitation contracts. These rates were then aggregated and adjusted to take into account regional variations in costs. The unit rates used in the study are summarized in Table A1.

Table A1. Unit rates used for the economic analysis (after Mitchell and Walker, 1985)

Measure or Material	Rand /m ²
150 mm G1 base and prime coat	4.20
125 mm asphalt base including prime coat	15.00
235 mm concrete slab including texturing, curing, joints and tie-bars	22.00
40 mm asphalt wearing course with rolled in chips and tack coat	7.00
40 mm asphalt overlay	7.00
100 mm asphalt overlay	17.50
Single seal	1.50
Joint repairs	0.50
300 mm cement stabilized subbase (C3) (build in 2 150 mm layers)	3.50
100 mm cement stabilized subbase (C2) with prime coat	5.00
150 mm selected subgrade	0.50

Based on the above-noted assumptions and the rates in Table A1, Mitchell and Walker (1985) calculated the following present worth of costs for the three pavement types considered:

Table A2. Present Worth-Of-Cost (PWOC) for different pavement types (after Mitchell and Walker, 1985) (assuming a 6% discount rate)

Pavement Type	PWOC (excluding RUDC) (R/m ²)	Present Worth of RUDC (R/m ²)	PWOC Including RUDC (R/m ²)
Crushed Stone (with 40 mm overlay at 18 years)	17.25	2.35	19.60
Crushed Stone (with 100 mm overlay at 18 years)	20.20	4.60	22.50
Bituminous Base, 100 mm thick	24.4	2.30	26.70
Bituminous Base, 125 mm thick	27.2	2.30	29.50
Concrete	26.5	Zero	26.50

Note: RUDC = Road User Delay Costs, calculated at 80% of the PWOC of maintenance

From the values shown in Table A2, and based on other aspects of their analysis not shown here, Mitchell and Walker (1985) concluded the following:

- The Crushed Stone (G1) base pavement was the most economical, particularly if the rehabilitation at 18 years consisted of a 40 mm asphalt overlay (as opposed to a 100 mm overlay);
- The PWOC of the concrete and bituminous base pavements are close enough to conclude that there is no significant cost difference between these two pavement types, and that other factors such as strategy, stimulation of competition also need to be considered.

- For discount rates ranging from 6 to 10 percent (considered to be a practical range in the Mitchell and Walker study of 1985), the discount rate is not a determining factor for the PWOC of the pavement types considered.

Most important for the evaluation of the benefits of the HVS investigations on G1 pavements, is the saving that can be realised if a G1 base pavement was built instead of a concrete or bituminous base pavement roughly around 1985.

Based on the analysis of Mitchell and Walker (1985), this saving would have ranged between R9.90 and R4.00 per square metre, depending on the type of rehabilitation performed on the G1 pavement, and the alternative it was compared to. For a lane construction width of 3.9 m, this would translate to a saving of R 31,200 and R 77,220 per two lane kilometre.

Re-Evaluation of Life Cycle Costs

As noted earlier, the Mitchell and Walker study was performed at the time when most of the findings of the HVS investigations on G1 material were being assimilated by the South African road building industry. The findings of Mitchell and Walker are therefore regarded as being quite appropriate for evaluating any cost savings resulting from the use of G1 base pavements in lieu of the more expensive concrete and asphalt base options. However, experience gained with regards to pavement design and construction since the time of the Mitchell and Walker study, suggest that some of the assumptions of the Mitchell and Walker study can be improved on. These aspects include:

- The assumed pavement structures for the different design options differ somewhat from actual constructed pavements. Specifically, case studies show that concrete base pavements are typically constructed with more than only 100 mm of cemented subbase support.
- The maintenance required for asphalt pavements. Since asphalt is a cohesive material, it typically deteriorates by cracking and disintegration. Because of problems with reflection cracking, rehabilitation of an asphalt base pavement seldom consists only of an overlay, as was assumed in the study by Mitchell and Walker. Case studies reported by the South African National Roads Agency^{Note 1}, suggest that, in the case of asphalt base pavements, deeper reworking, which would replace both the asphalt base and surfacing, is often required. One case study (on National Route 3) showed that replacement of the asphalt base and surfacing was needed in year 13. For calculation of future maintenance cost, a similar treatment was assumed in year 23.
- It was noted in the Mitchell and Walker study that the maintenance cost for concrete roads was a somewhat unknown factor at the time of publication. Mitchell and Walker thus assumed a single maintenance action, at age 20 years, and at a unit cost of R0.50 per m². However, case studies suggest that more frequent and costly maintenance is required on concrete roads, compared to what was assumed in the Mitchell and Walker study. A case study reported by SANRAL show that panel repairs and joint seal replacement was performed in year 12, at a unit cost of R3.15 per m² (discounted to 1984). For calculation of future maintenance cost, another such treatment was assumed in year 24.

Note 1: Information is based on a presentation made by Mr. Dennis Rossmann of SANRAL, to the Cementitious Forum, and provided to the author by Mr. Rossmann.

- With regards to the G1 base pavement, case studies investigated suggest that a surface seal is often placed in years 8 to 12 (as assumed in the study by Mitchell and Walker), but that reworking and stabilization using bitumen emulsion and/or cement is often considered when the pavement reaches a terminal condition (typically at ages close to or greater than 20 years). The cost of maintenance for the G1 base pavement thus also needs to be adjusted.

Using the above information as guidelines, a re-evaluation of pavement life cycle cost was performed. In this evaluation, the material costs as assumed by Mitchell and Walker in 1985 were adopted, since these are averaged costs that are deemed to be most appropriate for construction taking place between 1980 and 1990, when the impact of the HVS investigations on G1 materials was perhaps greatest^{Note 2}. Specific assumptions of the re-evaluation are:

- For the G1 base pavement, a structural rehabilitation was assumed in year 18. It was further assumed that this rehabilitation would consist of reworking the G1 base and stabilizing the base with bitumen emulsion. 1985 costs for the emulsion stabilization of an existing base are not available. A conservative (i.e. high) cost of R12 per m² was adopted. This cost is roughly 80 per cent of the cost of a new asphalt base, and is deemed to be realistic, if somewhat conservative.
- For the asphalt base pavement, a structural rehabilitation was assumed in year 18. For this rehabilitation, it was assumed that the existing asphalt base would be removed and replaced, with some areas still left in place, after which an asphalt surfacing would be placed over the entire section. For the removal and replacement of the base, a rate of R12 per m² was assumed. This rate is less than the rate for a new asphalt base, and reflects the fact that some intact and sound areas will not be rehabilitated (roughly 20 per cent of the area).
- For the concrete pavement, maintenance of slabs and joints was assumed at year 12 and year 24. The cost of this treatment was based on the discounted cost obtained from the SANRAL case study noted earlier.
- Since all alternatives require two maintenance or rehabilitation interventions, the road user cost for all alternatives is assumed to be similar and is thus not explicitly taken into account.

A summary of the total PWOC is shown in Table B3, while Table B4 shows the savings effected if a G1 base pavement is used instead of an asphalt or concrete base pavement. Detailed calculations are shown in Figures B3 to B5.

Note 2: An evaluation of typical material costs in the 1980's and 1990's suggest that the cost of pavement materials in the 1990's is significantly higher than those reported in the 1985 study by Mitchell and Walker. This implies either a high inflation rate or a discontinuity in material costs. However, a similar study conducted in 1979 by Freeme and Straus (Proceedings, 3rd CAPSA, Durban, 1979) show that the cost used by Mitchell and Walker are in line with the norms of that period.

Table B3: PWOC for Different Design Alternatives

Discount Rate	Cost Per Square Metre		
	G1 Base Pavement	Asphalt Base Pavement	Concrete Pavement
4 %	R 26.17	R 36.39	R 32.45
8 %	R 21.27	R 31.45	R 31.00
12 %	R 18.78	R 28.95	R 30.27

Table B4: Savings Effected If G1 Base Pavement Is Used

Discount Rate	Saving Per Square Metre		
	G1 Base Pavement	Asphalt Base Pavement	Concrete Pavement
4 %	R -	R 10.22	R 6.27
8 %	R -	R 10.18	R 9.73
12 %	R -	R 10.17	R 11.49

Table B4 shows that, regardless of the discount rate, the saving per square metre is typically around R10 to R11 per square metre. This saving is close to the upper limit saving of R9.90 reported in the study by Mitchell and Walker, but differs significantly from the lower limit of R 4.40. This is mainly because the study by Mitchell and Walker included a 100 mm thick asphalt base pavement, which is not considered to be comparable to the other design alternatives for this re-evaluation of life-cycle costs.

In general, the re-evaluation of life cycle costs presented here yields similar results to those of Freeme and Walker (1985). Specifically, it can be stated with some certainty that a general life cycle cost saving of between R9 and R12 per square metre could be realized if a G1 base pavement was constructed instead of an asphalt or concrete base pavement.

Year	Base Year (Year 0)	
Situation	Initial Construction	
Structure & Cost	40 mm Asphalt Surfacing	R 7.00
	150 mm Granular Base	R 4.20
	350 mm Cemented Subbase	R 4.00
	150 mm G7 Selected Layer	R 0.50
Cost Calculation	Total Cost per square metre	R 15.70
	Discount Period	0
	PWOC at discount rate of 4%	R 15.70
	PWOC at discount rate of 8%	R 15.70
PWOC at discount rate of 12%	R 15.70	

Year	Year 8	
Situation	First Surface Seal	
Treatment	Single Seal	R 1.50
Existing Structure	40 mm Asphalt Surfacing	R -
	150 mm Granular Base	R -
	350 mm Cemented Subbase	R -
	150 mm G7 Selected Layer	R -
Cost Calculation	Total Cost per square metre	R 1.50
	Discount Period	8
	PWOC at discount rate of 4%	R 1.10
	PWOC at discount rate of 8%	R 0.81
PWOC at discount rate of 12%	R 0.61	

Year	Year 18	
Situation	Structural Rehabilitation	
Treatment	40 mm Asphalt Surfacing	R 7.00
	Rework and Treat Base as ETB	R 12.00
Existing Structure	40 mm Asphalt Surfacing	R -
	150 mm Granular Base	R -
	350 mm Cemented Subbase	R -
	150 mm G7 Selected Layer	R -
Cost Calculation	Total Cost per square metre	R 19.00
	Discount Period	18
	PWOC at discount rate of 4%	R 9.38
	PWOC at discount rate of 8%	R 4.75
PWOC at discount rate of 12%	R 2.47	

Total PWOC at Discount Rate of 4% =	R 26.17
Total PWOC at Discount Rate of 8% =	R 21.27
Total PWOC at Discount Rate of 12% =	R 18.78
Note: All costs shown are per square metre	

Figure B3: Life Cycle Cost Estimate: G1 Base Pavement

Year	Base Year	
Situation	Initial Construction	
Structure & Cost	40 mm Asphalt Surfacing	R 7.00
	125 mm Asphalt Base	R 15.00
	300 mm C3/C4 Cemented Subbase	R 3.50
	150 mm G7 Selected Layer	R 0.50
Cost Calculation	Total Cost per square metre	R 26.00
	Discount Period	0
	PWOC at discount rate of 4%	R 26.00
	PWOC at discount rate of 8%	R 26.00
	PWOC at discount rate of 12%	R 26.00

Year	Year 10	
Situation	First Surface Seal	
Treatment	Single Seal	R 1.50
Existing Structure	40 mm Asphalt Surfacing	R -
	125 mm Asphalt Base	R -
	300 mm C3/C4 Cemented Subbase	R -
	150 mm G7 Selected Layer	R -
Cost Calculation	Total Cost per square metre	R 1.50
	Discount Period	10
	PWOC at discount rate of 4%	R 1.01
	PWOC at discount rate of 8%	R 0.69
	PWOC at discount rate of 12%	R 0.48

Year	Year 18	
Situation	Structural Rehabilitation	
Treatment	40 mm Asphalt Surfacing	R 7.00
	Partially Remove & Replace Base	R 12.00
Existing Structure	40 mm Asphalt Surfacing	R -
	150 mm Granular Base	R -
	350 mm Cemented Subbase	R -
	150 mm G7 Selected Layer	R -
Cost Calculation	Total Cost per square metre	R 19.00
	Discount Period	18
	PWOC at discount rate of 4%	R 9.38
	PWOC at discount rate of 8%	R 4.75
	PWOC at discount rate of 12%	R 2.47

Total PWOC at Discount Rate of 4% =	R 36.39
Total PWOC at Discount Rate of 8% =	R 31.45
Total PWOC at Discount Rate of 12% =	R 28.95
Note: All costs shown are per square metre	

Figure B4: Life Cycle Cost Estimate: Asphalt Base Pavement

Year	Base Year	
Situation	Initial Construction	
Structure & Cost	235 mm Jointed Concrete Slabs	R 22.00
	100 mm C2 Cemented Subbase	R 5.00
	150 mm C4 Cemented Subbase	R 1.75
	150 mm G7 Selected Layer	R 0.50
Cost Calculation	Total Cost per square metre	R 29.25
	Discount Period	0
	PWOC at discount rate of 4%	R 29.25
	PWOC at discount rate of 8%	R 29.25
	PWOC at discount rate of 12%	R 29.25
Year	Year 12	
Situation	Panel Repairs and Joint Seal Replacement	
Treatment	Maintenance	R 3.15
Existing Structure	40 mm Asphalt Surfacing	R -
	125 mm Asphalt Base	R -
	300 mm C3/C4 Cemented Subbase	R -
	150 mm G7 Selected Layer	R -
Cost Calculation	Total Cost per square metre	R 3.15
	Discount Period	12
	PWOC at discount rate of 4%	R 1.97
	PWOC at discount rate of 8%	R 1.25
	PWOC at discount rate of 12%	R 0.81
Year	Year 24	
Situation	Panel Repairs and Joint Seal Replacement	
Treatment	Maintenance	R 3.15
Existing Structure	40 mm Asphalt Surfacing	R -
	125 mm Asphalt Base	R -
	300 mm C3/C4 Cemented Subbase	R -
	150 mm G7 Selected Layer	R -
Cost Calculation	Total Cost per square metre	R 3.15
	Discount Period	24
	PWOC at discount rate of 4%	R 1.23
	PWOC at discount rate of 8%	R 0.50
	PWOC at discount rate of 12%	R 0.21
Total PWOC at Discount Rate of 4% =		R 32.45
Total PWOC at Discount Rate of 8% =		R 31.00
Total PWOC at Discount Rate of 12% =		R 30.27
Note: All costs shown are per square metre		

Figure B5: Life Cycle Cost Estimate: Concrete Pavement

APPENDIX C

**G1 PAVEMENT DISTRIBUTION FOR GAUTRANS AND
SANRAL ROADS**

Introduction

In this Appendix, the distribution of G1 base pavements for the Gautrans and SANRAL road network is summarized. A specific objective of this summary is to obtain an indication of the approximate lane-km of road with G1 bases in different traffic categories. The pavement type data used was obtained from Mr. Derek Roux (for Gautrans) and Mr. Louw Kannemeyer (for SANRAL).

Traffic Classification

The pavement data provided by Gautrans and SANRAL contains network level information only. As such, any detailed assessment of the pavement traffic class required additional calculations and assumptions. Specifically, the data generally only contained the Annual Average Daily Traffic (AADT) and in some instances the percentage of heavy vehicles. Thus, in order to obtain the approximate cumulative standard axles over a typical 25 year design period, some assumptions have to be made. These are stated below:

Heavy Vehicle Percentage:

Where the percentage of heavy vehicles was not available, a heavy vehicle contribution of 8 per cent was assumed.

Lane Factor:

A lane factor of 0.8 was assumed for cases where there were more than 1 lane per direction.

Growth Rate:

A nominal heavy vehicle growth rate of 4 per cent was assumed in all cases.

E80 per Heavy Vehicle Factor

The factor used to convert heavy vehicles to equivalent standard axles (E80) was 1.2 in all instances. It is believed that this factor is conservative in the context of this investigation, since it is likely to underestimate the actual number of E80's per day on most roads.

The procedure for classifying G1 base pavements into different design categories was performed using the following steps:

1. The number of heavy vehicles per day was first determined using the AADT with the actual or assumed heavy vehicle percentage.
2. The number of heavy vehicles per day was then adjusted where needed for the design lane by using the assumed lane factor of 0.8
3. The E80's per day were then determined using the assumed E80 per heavy vehicle factor.

For a 25 year design period, and using the above-noted assumptions and steps, the pavements could be classified based on the daily E80 counts shown in Table C1.

Table C1: E80 Counts Used For Pavement Classification

Daily E80's	25 Year Design Traffic Category
0 to 65	0 to 1 MISA
65 to 190	1 to 3 MISA
190 to 510	3 to 8 MISA
510 to 760	8 to 12 MISA
760 to 1900	12 to 30 MISA
> 1900	> 30 MISA

Classification Results

A computer program was used to classify all pavements into the design traffic categories shown in Table C1. In this classification process, data tables containing pavement structural information were joined with tables containing traffic data. The join operation only considered sections for which a definitive match between construction segment and traffic count segment location could be found. Since the section location for the construction and traffic count did not always coincide, a traffic classification could not be made for all of the sections. As a result, a small percentage of sections were not included in the classification.

Also, only those sections constructed between 1980 and 1990 were included in this summary. This is the period in which the findings of the HVS investigations impacted most significantly on the South African road building industry, and is also the benefit period allocated to the HVS investigation findings on G1 base pavements.

The lane-km totals presented in this section will thus be less than the total lane-km length of G1 pavements found on the Gautrans and SANRAL networks. In the context of this study, this means that the estimation of savings realized by G1 construction would be conservative (i.e. it would be underestimated).

A summary of the G1 base pavements falling in different 25 year design classes is shown in Tables C2 and C3 for the Gautrans and SANRAL networks, respectively. These data are summarized graphically in Figures C1 and C2.

Table C2: Classification of G1 base pavements on the Gautrans Network

25 Year Design Class	E80's Per Day		Number of Sections	Lane-Km in Class
	From	To		
0-1MISA	0	65	5	16
1-3 MISA	65	190	5	40
3-8 MISA	190	510	21	164
8-12 MISA	510	760	5	33
12-30 MISA	760	1900	17	102
>30 MISA	1900	20000	1	3

Table C2: Classification of G1 base pavements on the SANRAL Network

25 Year Design Class	E80's Per Day		Number of Sections	Lane-Km in Class
	From	To		
0-1MISA	0	65	0	0
1-3 MISA	65	190	11	451
3-8 MISA	190	510	32	926
8-12 MISA	510	760	0	0
12-30 MISA	760	1900	4	29
>30 MISA	1900	20000	3	122

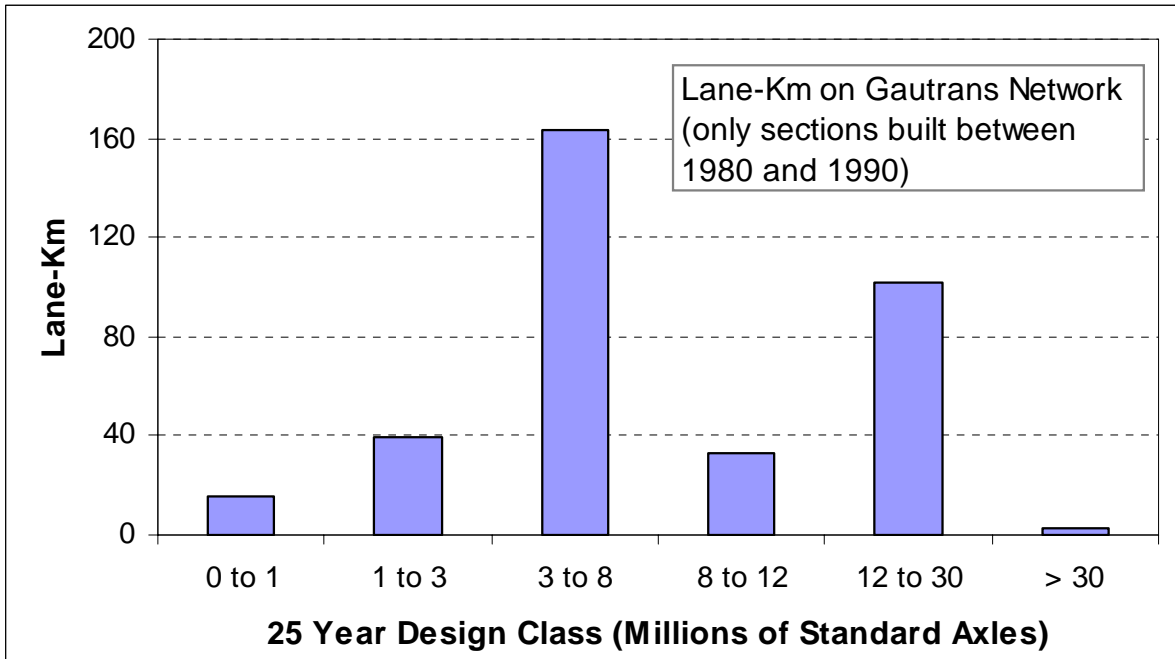


Figure C1: Classification of Lane-Km on Gautrans Network

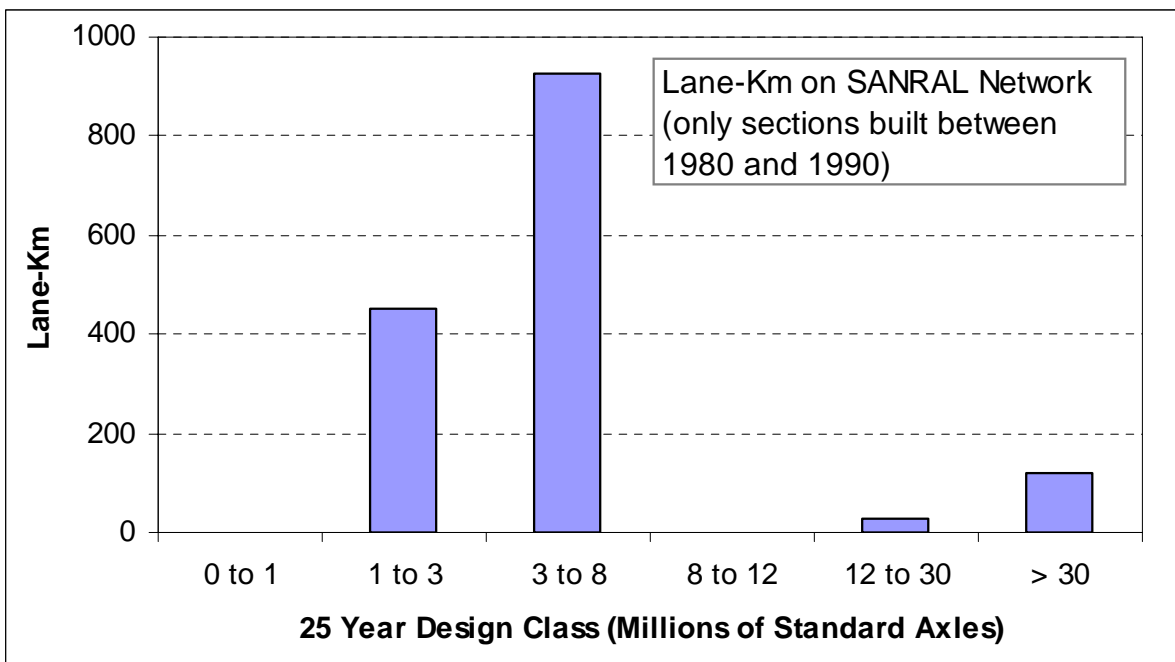


Figure C2: Classification of Lane-Km on SANRAL Network

APPENDIX D

RECORD OF INTERVIEWS WITH INDUSTRY EXPERTS ON G1 MATERIALS DESIGN AND CONSTRUCTION

Record of Interview

Interview With: **Mr. J.P. Nothnagel (BN)**

Interview Date: 29 April, 2004

Interview Duration: Approximately 3 hours

Context: Mr. Nothnagel was a former Executive Regional Director at the South African National Roads Agency. Mr Nothnagel is widely regarded as an expert in pavement design and construction. Mr. Nothnagel was influential in shaping many of the design recommendations and material specifications that are currently implemented in southern Africa.

Details of interview

General / Background:

- A problem statement was discussed and the need for quantifying research benefits was provided. BN recommended that Janine Bothma of SANRAL be contacted regarding SANRAL's method for evaluating the socio-economic benefits of research. JB was apparently involved in doing socio-economic assessments for SANRAL to determine socio-economic benefits of building roads in certain areas etc. BN also recommended we get details of a "Naude" at Potch University, involved in such evaluations.
- BN recommended that we also interview the more academic practitioners such as Louw Kannemeyer, who could provide a realistic assessment on whether or not the design methods can actually predict performance. BN suggested I contact his former secretary Jogi (012) 426 6202 or 082 904 2378 to obtain Louw's cell phone number.
- Other names mentioned were Ettiene de Villiers, Brian Spottiswoode and Paul Olivier.
- BN also mentioned that when the HVS was operating in an area, it always created a hub of interest in the area. Practitioners were keen to obtain knowledge and information if the HVS was operating in an area (e.g. KZN).
- The first specification for Roads and Bridges was put together in 1978, as a joint effort between TPA and NDOT.
- BN agrees that G1 development was a TPA initiative, and the TPA drove the concept of a very high quality Crushed Stone, compacted with more energy and achieving a higher compaction. This soon led to mod. AASHTO densities of 105%, which suggested the need for an alternative density measurement method. This gave rise to the apparent relative density specification. The TPA also saw the requirement for "slush rolling". BN opinion is that in the early stages the G1 technology was mainly a construction technology.
- In the Cape Province, fines from other origins were added to crushed rock. No distinction was made between different types of crusher run. However, it became clear that the TPA could achieve clearly superior product through their very specific construction method. It soon became apparent that this material should also be handled differently in design (especially in the SN method).
- The SN design method was never really used well with G1 materials. At that stage there were many questions and schools of thought about the behaviour of G1 type materials.

Aside:

BN noted the importance of the type of crushing method. According to BN, the old method (around 1980) produced very sharp and angular aggregates. Modern "Barmac" crushing produces more rounded and less sharp aggregates. A Barmac aggregate at 86% ARD has less than 50% of the shear strength of an 88% ARD layer.

The method of crushing had changed since the 1980's, but no adjustment had been made to the specifications. This is an important gap in the current specification and construction methodology.

On Specifications:

- On the development of the specifications: Originally, the specification was for 88% ARD. Then statistical acceptance method came into use, and it became apparent that contractors had to get around 90% average ARD to meet the 88% spec. The contractors complained and the specification was changed to 86% to 88% ARD. Later the statistical method was improved, BUT the 86% ARD specification remained unchanged.
- Another significant change was the introduction of nuclear gauges. The probe method especially gave problems since it did not test the top of the layer as well as the backscatter method did.
- BN noted that, if the top 75 mm of the layer was well compacted, then in his opinion the rest of the layer will also be well compacted.
- BN feels that optimal use was not made of HVS knowledge to adjust specifications. The HVS work tended to focus mainly on design aspects and not so much on construction and specifications. BN feels that the HVS contribution to specifications should probably be less than 30%. Most of the contribution to specification changes came from knowledgeable practitioners.

On Design Practice Before HVS Work On G1's

- BN agrees that there was very little confidence in the performance of G1 base pavements for high traffic classes, especially for areas outside of the Witwatersrand where the method had not been widely implemented.
- Around 1980, concrete pavements were widely favoured by the NDOT (Mitchell). In general, it was felt that a more natural, unbound material like G1 could not be compared with a highly refined technology such as concrete pavements.
- There was significant resistance to change to G1 type pavements.
- The TPA had significant confidence in the use of G1 base pavements, but other client bodies and practitioners felt that the TPA only had experience in the Witwatersrand area, and had no knowledge of other areas (especially the wet climate zones).

HVS Practice

- There were many questions when the HVS originally started working.
- What about LTPP? Doubts about bi-directional trafficking etc.

Main Findings of G1 Experiments

- BN agrees with the findings as documented. Some additional notes were made, as recorded below:
- The thickness of 150 mm was shown to be optimal (over 200 mm at the time). However, it was later found that 125 mm is actually even better.

Main HVS Impacts

- BN agrees with the confidence obtained from HVS to use G1 in 12 to 50 MISA class. BN noted several pavements that would have been either concrete or asphalt base pavements but were constructed as G1 owing to the information obtained from HVS experiments. BN agrees with the 80% contribution ratio. Important specific roads are noted below:
- Sections of N1 North of Warmbaths: These were all originally designed as concrete roads. They were later re-designed and built as G1 pavements. Specifically mentioned Middelfontein to Pietersburg section, which was built as a G1 in the 1980s. This road was in concept designed and cost estimated as a concrete road. BN feels that the change to G1 was highly influenced by HVS experiment findings.
- N4 East of Nelspruit: would probably have been a black base pavement.
- N4 Middelburg to Wonderfontein: would have been black base or concrete.
- According to BN, it is highly likely that the above pavements would have been asphalt base or concrete pavements if the HVS experiment results were not available.
- In Natal there are several sections of the N2 North Coast (up to Mtinzine) that would most likely have been black base pavements. Dennis Rossmann will have the details.
- Natal is an important province. In that area, there was a very fixed opinion that G1 base pavements would not work.
- East London bus route (Gary Swart at Bradford Conning will have details). Background: this road was needed as a bus route and was planned as an asphalt base. Ninham Shands designed and design and construction was rushed. BN designed? Road as a G1, based on HVS experiences. This road was built in a wet area and there was a lot of emphasis on the fact that it was a bus route with a high potential for overloading.
- Outside Port Elizabeth (also ask Gary Swart): Sections of (N2 - ??? Swartkops, just North of PE) first built as asphalt base. Other sections later built as G1.
- Regarding the life cycle cost of concrete pavements. BN agrees that the maintenance cost was underestimated in the 1980's. Dennis Rossmann did a presentation at BMLC in which the maintenance cost was studied for actual pavements (only short study). This showed that the maintenance cost of concrete roads was underestimated. However, BN notes that the structural capacity was also underestimated and that this would balance out. The problems on concrete pavements are often a result of poor construction and not related to design or the concrete concept.

General Benefits

- BN noted that this study of HVS benefits was very important, not only for Gautrans but also for SANRAL and some other provinces. The report should appreciate that and also provide details that are useful to SANRAL and others.
- It was noted that the HVS impacted significantly on the UNDERSTANDING of pavements in general, and of the pavement operating as a system. There is a lot of economic value in this.

- The increased understanding meant that labour intensive and other novel design and construction methods could now be considered and developed, and not just standard concrete or asphalt pavements based on the overseas model.
- At a TRB, there was a special presentation made by SANRAL, with a video made by AA Loudon), regarding RSA G1 technology.
- Career Development: apart from the development of highly skilled practitioners, the HVS work also rubbed off on general practitioners. A hub of interest was created by HVS experiments and reporting of findings.
- HVS work also contributed to tyre pressure interest, and this may impact on laws regarding tyre pressures.

Record of Interview

Interview With: **Prof. E. Horak (EH)**
Interview Date: 17 May, 2004
Interview Duration: Approximately 60 minutes

Context: Prof. Horak is the head of the Civil Engineering Department of the University of Pretoria. Prof. Horak was formerly associated with CSIR Transportek and has contributed significantly to the development and implementation of pavement technology in South Africa.

Details of interview

General / Background:

- A problem statement was discussed and the need for quantifying research benefits was provided.
- EH noted that the AASHTO road test had an impact on the development of the CSIR test site in Silverton, Pretoria. A test track was originally constructed in Silverton, and the original thinking was roughly a simulation of the AASHTO concept. The cost elements associated with the test track then led to the development of the HVS.
- The HVS was initially used as a proof tester. Most pavements, specifically asphalt and concrete pavements, were designed not to fail.
- The political environment at the time was such that the HVS had to show that the pavement would not fail. This meant that the knowledge gained from the experiments were not as significant at that time.
- EH noted that many other parties should receive credit for the development of G1 technology. In the late 1970's practitioners and researchers still struggled to describe the emerging G1 technology.
- There were a lot of political arguments amongst role players and material engineers. Agreement could not be reached on elements such as material types, required densities etc.
- The definition or circumscription of G1 technology was very difficult at the time (mid to late 1970's)
- There was plenty of collective work available, but this was not really defined research that helped to synthesize and understand underlying mechanisms.
- Early projections showed certain trends and the HVS proved those trends.
- EH noted the significance of Dr. JH Maree's MSc. Thesis on Crushed Stone materials, and noted that this played a significant role in the initial development of G1 technology. Maree's work essentially laid the fundamental foundation for what was to follow from HVS work.

Acceptance of G1 for 12 to 50 MISA

- EH noted that he agrees with this impact and that the role of the HVS investigations in this regard was such that the HVS contributed at least 80 per cent to this impact.
- It was pointed out to EH that other persons interviewed noted that the N1 north of Warmbaths was originally designed as a concrete road but later built as a G1, partly due to the dissemination of HVS investigations on G1 base pavements. EH agrees with this,

and noted that there was initially a tendency to lean toward the European design approach which uses thicker concrete or asphalt base pavements.

The Suitability of G1 for Wet Climate Zones

- EH agrees with this impact, and noted that, at proof testing level, the HVS showed clearly that G1 base pavements can be used in wet climate zones.
- The contribution ratio for the HVS toward this impact should be around 60 per cent, since much of the foundation was laid by the work of Dr. JH Maree.

The Use of an n-Value of Less Than 4.0 for G1 Base Pavements

- EH agrees with this impact, and that the contribution ratio should be roughly 80 per cent.
- EH also noted that overseas researchers at the time showed little credibility toward HVS test results, owing to the AASHTO road test paradigm. The dissemination of the HVS results at international conferences etc. helped to transcend the AASHTO paradigm and greatly improved understanding of pavement behaviour.

The use of 150 mm G1 instead of 200 mm

- EH agreed with this impact but noted that the work of Dr. JH Maree also contributed greatly.
- The HVS assisted in bringing to the forefront the systems thinking associated with pavement behaviour, which is related to this impact.

The Difference between G1 and G2 Materials

- EH agreed with this impact but noted that the HVS sometimes contributed to the controversy. The contribution of the HVS findings to this impact should be around 30 per cent.
- EH noted that the McLean Town tests showed the importance of Crushed Stone grading and the quality of fine material.

Other Benefits / Process Benefits / General Issues

- The HVS work also contributed to the understanding of cemented gravels, specifically on the understanding of pavements with lightly cemented bases and surface seals. The HVS work on these types of pavements gave credibility to the use of lightly cemented weaker materials for load traffic applications.
- EH pointed out that Dr. JH Maree also performed work on emulsion treated materials.
- The dissemination of HVS findings was effected through international conferences.
- At the Annual Transport Convention in 1985, an entire session was devoted to HVS testing. Many international researchers travelled to South Africa to attend this session/conference.
- EH also stressed that the HVS concept is not concerned only with the HVS machine, but also with the technology offering associated with the machine, such as Multi-Depth Deflectometers (MDD), Road Surface Deflectometers (RSD), etc. When an HVS is sold to an overseas or local agency, it is an entire technology offering that is sold, and not just an HVS machine.

Record of Interview

Interview With: **Dr. Pieter Strauss (PS)**
Interview Date: 18 May, 2004
Interview Duration: Approximately 80 minutes

Context: Dr. Strauss was a former director of BKS Consulting, and presently works as an independent consultant. Dr. Strauss is an acknowledged expert in flexible and concrete pavement design and has been influential in South African pavement research and development over the past two decades.

Details of interview

General / Background:

- A problem statement was discussed and the need for quantifying research benefits was provided.
- PS noted that his first exposure to high quality Crushed Stone was in 1965, on the Ben Schoeman highway construction project, where an 8 inch Crushed Stone was placed on a stabilized subbase.
- The use of a Crushed Stone over a cemented subbase was also implemented on other projects such as the Buccleuch Interchange and Bronkhorstpruit Roads. These were all Department of Transport roads, designed by VKE Consulting.
- On the Ben Schoeman construction, the contractors already started referring to the slushing of the base.
- PS also noted that the perception was that the cemented base was used mainly to ensure that the compaction and proper slushing could be achieved on the base layer.
- The Department of Transport initiated the drive for a proper norm for compaction densities on Crushed Stone. The challenge was to quantify the "slushing concept".
- After roughly 1972 the specific gravity measurement methods started being used. The Cape Provincial Administration did not use or support slushing, and also did not support the use of a cemented subbase.
- Around 1979, however, the Cape Provincial Administration, and specifically Mr. Etienne de Villiers, started to support the slushing concept. There were several arguments or differences around the use of slushing and how to get maximum density.
- According to PS, a Crushed Stone over a cemented subbase was seen as a prime type of pavement at that time.
- With the advent of the mechanistic design approach, the focus shifted somewhat to scientific explorations.
- According to PS, the Freeme (1980) document about pavement selection (which did not include G1 base pavements for 12 to 50 MISA) was highly influenced by Prof. F. Hugo's work, some of which was implemented on the design of the (then) Jan Smuts airport.

Acceptance of G1 for 12 to 50 MISA

- PS noted that a key problem at the time was that practitioners and researchers did not know what the boundaries of G1 materials applications were. The real advantage of the HVS was the fact that it quantified what knowledgeable practitioners already knew intuitively at that stage.
- PS agreed that the HVS conclusively showed that the G1 base over a thick cemented subbase was the best unbound base design.

- PS agrees that the HVS was influential in showing that G1 base pavements were suitable for 12 to 50 MISA design situations.
- PS agrees that the HVS contribution to this impact is around 80 per cent, but only if the mechanistic design concept is included as an HVS investigation result. If the HVS investigations are seen as an independent element, then the contribution should be around 60 per cent.
- PS could not recall any specific roads where a G1 was used instead of an earlier planned concrete or asphalt base, and was not aware of the change in design for the N1 north of Warmbaths.
- PS noted that the HVS investigations provided a handle to the knowledge of Crushed Stone behaviour and helped to extrapolate over 12 MISA traffic requirement with more confidence.

The Suitability of G1 for Wet Climate Zones

- PS agrees that the HVS was influential to this impact, and also agrees with the assigned 80 per cent contribution, if the mechanistic design is included as part of the HVS findings. If not, the contribution should be closer to 50 per cent.

The Use of an n-Value of Less Than 4.0 for G1 Base Pavements

- PS agrees that the HVS was influential to this impact, and also agrees with the assigned 80 per cent contribution, if the mechanistic design is included as part of the HVS findings. If not, the contribution should be closer to 50 per cent.

The use of 150 mm G1 instead of 200 mm

- PS agrees with this impact, and feels that a 30 per cent contribution awarded to the HVS investigations is appropriate.

The Difference between G1 and G2 Materials

- PS agrees with this finding and feels that the HVS played a pivotal role in this regard. The assigned HVS contribution should be increased to at least 60 per cent.

Other Benefits / Process Benefits / General Issues

- PS noted that Gauteng is indeed the "Smart Province", and is technologically regarded as one of the best provincial administrations with regards to pavement design and construction. Even internationally, Gauteng is considered to be a highly knowledgeable province.
- With regards to science and technology excellence, PS noted that South African consultants are held in high regard worldwide. In Africa especially, other international consultants tend to design according to the AASHTO model (which uses much thicker pavements). South African consultants, owing partly to the contribution of the HVS, generally recommend and implement more cost effective designs.
- PS also noted that the Accelerated Pavement Testing (APT) technology is to a large extent underlain by the HVS concept and the original HVS development.

Record of Interview

Interview With: **Mr. Louw Kannemeyer (LK)**

Interview Date: 18 May, 2004

Interview Duration: Approximately 40 minutes

Context: Mr. Kannemeyer is affiliated to the South African Roads Agency and is responsible for management of the Roads Agency's pavement management system, amongst other responsibilities. Mr Kannemeyer is acknowledged as an expert on pavement condition measurement and has extensive experience on the condition and performance of the South African National Road system.

Details of interview

General / Background:

- A problem statement was discussed and the need for quantifying research benefits was provided.
- LK was asked about the layout of some of the national route sections noted by Mr. Basie Nothnagel in the interview with him (e.g. N2 North Coast, N1 North – a 4 lane undivided road from Warmbaths to Pietersburg), N4 near Middelburg – dual carriageway, N4 east of Nelspruit – 2 lane with paved shoulders and climbing lanes).

Acceptance of G1 for 12 to 50 MISA

- LK agrees with this impact and noted that, without the benefit of HVS testing, it would have required approximately 15 years of long term pavement performance data to obtain the same level of information as was obtained from the HVS investigations on G1 materials.
- LK agrees with Mr. Basie Nothnagel's statement that some of the N2 North Coast sections would have been concrete, but was built as a G1 for economic reasons.
- LK noted another section, the N12, which carries very heavy traffic and which would perhaps have been a concrete road was it not for the confidence instilled in G1 by the HVS investigations.

The Suitability of G1 for Wet Climate Zones

- LK commented that in the wet Kwazulu-Natal area, there is not really good G1 material, especially in the northern areas.
- LK also stressed the importance of timely maintenance on G1 base pavements in the wet areas.
- LK noted that the G1b or G2 base with a 13 mm Cape Seal is in his opinion the worst pavement to build in a wet weather zone. This is because of the importance of material quality, especially in wet zones.

The Use of an n-Value of Less Than 4.0 for G1 Base Pavements

- LK agrees with this impact and noted that, based on SANRAL experience, the n-value of 3.5 is roughly appropriate for G1 base over cemented subbase pavements.
- LK noted, however, that many practitioners still use a value of 4.2. As a result, many roads are completely over designed. LK mentioned the example of the N1 near Pretoria,

which was designed for a short design life, but has already provided good service for approximately 30 years. Over-design has an impact on budgeting and effective allocation of funding.

The use of 150 mm G1 instead of 200 mm

- LK agrees with this impact;

The Difference between G1 and G2 Materials

- LK discussed some of the problems that SANRAL was experiencing with Crushed Stone material construction. At present, contractors meet the density specification of 86 per cent quite easily. LK noted that most construction problems are related to the slushing process. Contractors are offered an extra-over payment for increased compaction.

Record of Interview

Interview With: **Dr. J.H. Maree (JM)**
Interview Date: 4 May, 2004
Interview Duration: Approximately 80 minutes

Context: Dr. Maree was formerly Director of Transportek, CSIR, and was the lead researcher on the development of G1 technology in South Africa. Dr. Maree was also involved in many pavement designs in which G1 technology was implemented and was a key author of the TRH4 document.

Details of interview

General / Background:

- A problem statement was discussed and the need for quantifying research benefits was provided.
- The identified impacts and approximate contribution assigned to the HVS investigations was discussed. FJ pointed out that there was some discrepancy between the idea that G1 technology was not widely accepted in 1980, and the fact that G1 base pavements were already included in the 1980 Draft TRH4 catalogue. JM was asked to clarify this discrepancy if possible and to comment on the validity of the assigned impacts.

Acceptance of G1 for 12 to 50 MISA

- JM noted that at the time of the inclusion of G1 base pavements in the 1980 draft TRH4 document, there was a great controversy regarding the use and structural capacity of G1 base pavements.
- JM pointed out that there was not only doubt regarding the suitability of G1 base pavements for the 12 to 50 MISA design class, but also for the 3 to 12 MISA design class. The HVS experiments on G1 materials were instrumental in clarifying and dissolving this discrepancy.
- Several specific instances of G1 base pavements that have showed very good performance over a long period were noted and discussed. These include a section of G1 base pavement on the N3 near Pietermaritzburg, situated between two longer sections of concrete pavement. Also, sections of the N3 near Gilloolies, and the M1 in Johannesburg, from Corlett Drive to the city. The latter pavement has a G1 base and is now approximately 40 years old.
- JM noted that the HVS investigations also showed the importance of proper maintenance, specifically in preventing water from entering the G1 base layer.

The use of 150 mm G1 instead of 200 mm

- JM agreed with this impact and noted that 125 mm G1 base is really the optimal thickness to use for design. However, to limit reflection cracking, a 150 mm G1 base thickness is optimal.
- JM felt that the contribution of the HVS investigations on G1 materials to this impact is approximately 20 per cent.

Other Benefits / Process Benefits

- The HVS investigations on G1 base pavements greatly assisted in building an understanding of the failure mechanism of Crushed Stone base pavements. Once the mechanism of failure was understood, a design method could be formalized to extend the HVS experiment findings to other design situations.
- The South African mechanistic design method was calibrated using the findings of HVS investigations on G1 material (amongst other investigations). Again, once the models were calibrated, they could be extended to other design situations for which there was no longer a need to perform HVS testing, or to wait until sufficient performance data became available.
- The investigations on G1 base pavements (most of which used a cemented subbase) also contributed significantly to the technology for cemented subbases.
- The HVS investigations on G1 base pavements, and the resulting inclusion thereof in the TRH4 document also contributed toward the development of the "Blue Book" for design of Urban Roads. Before the HVS investigations on G1 base pavements the design approach for urban pavements was a "hodgepodge" of design approaches until the HVS investigations were published and disseminated.
- The HVS investigations also had an impact on the Southern African Developing Countries (SADC) approach to pavement design.
- HVS investigations also contributed greatly to science and technology. Many measurement devices and other developments were results of the HVS investigations. Included here are the Multi-Depth Deflectometer, the Rut meter, the Road Surface Deflectometer, etc. HVS technology development actually led to a suite of associated technologies. Transportek has or should have a brochure of all these associated technologies.

Record of Interview

Interview With: **Mr. Dennis Rossmann (DR)**

Interview Date: Via electronic mail, June, 2004

Interview Duration: Via electronic mail

Context: Mr. Rossmann is affiliated to the South African National Roads Agency. Mr Rossmann is an acknowledged expert on Crushed Stone and asphalt pavement design and construction, and has been influential in South African pavement design and construction developments over the past decade.

Identified Impacts

- **The suitability of G1 base pavements for the 12 to 50 MISA design traffic class was clearly proven**

Before HVS testing started, there was doubt whether a pavement with an unbound base was suitable for this high traffic demand, and before 1980 few designers would have prescribed a G1 base pavement for a 12 to 50 MISA design traffic situation. By 1982, the HVS investigations had provided conclusive evidence that a G1 base on a thick cemented subbase could sustain up to 50 MISA, provided that proper drainage is provided and the surfacing is well-maintained. A specific result of this impact was the extension of the Gautrans pavement design catalogue from an upper limit of 10 (before HVS test findings became known) to 100 Million Standard Axles (MISA) after HVS findings were assimilated.

The relative contribution of HVS investigations to this impact is estimated to be around 80 per cent. This contribution is based on the fact that HVS testing, owing to its accelerated nature, vastly accelerated the gathering of evidence to prove the suitability of G1 base pavements for the 12 to 50 MISA traffic class. To gather this evidence without access to HVS test results would have required a sustained and extensive long term pavement performance experiment that would have required sustained funding for at least a decade.

(If you agree with this impact – are there perhaps any specific roads you can recall where the road might have been an asphalt or concrete base pavement, but in the end was constructed as a G1 base, owing to some extent to the confidence obtained from HVS testing?)

Mr. Rossmann's Comments:

YES. On the South coast toll road, the original pavement design was a black base (BTB). This was changed in the very early 90's to a G1, which was ultimately constructed. Some sections of the North Coast Toll Road were also constructed in 1992 with a 150mm G1, while others received a 100mm BTB. 12 years later (2004) both types are performing well and have just received their 1st reseal (13/6,7mm). Although it must be added that they have as yet not reached the design traffic loading.

- **The low sensitivity of a high density G1 material to moisture proved that a G1 base pavement can be used in wet climate zones**

HVS investigations on G1 base pavements showed that a high density G1 material is very forgiving and not highly sensitive to moisture. As a result, G1 base pavements were being considered suitable for use in the wet climate zones of South Africa. In 1985, G1 base pavements were included in the TRH4 (1985) pavement design catalogue for wet regions (even for a 12 to 50 MISA design traffic class).

The relative contribution of HVS investigations to this impact is estimated to be around 80 per cent. This contribution is again based on the accelerated nature of HVS testing, and also on the controlled nature of HVS tests, which allowed precise monitoring of moisture in the different test pavements. To gather such evidence without access to HVS test results would have required a sustained and extensive long term pavement performance experiment that would have required sustained funding for at least a decade.

(Dennis, if you agree with this impact (and I know that is a GREAT IF!) – are there perhaps any specific roads you can recall that were influenced by this impact?)

Mr. Rossmann's Comments:

I can't argue that the results (and performance of some projects to date) indicate that G1's can work in a wet climate. However there are other factors that come into play. If you could pre-manufacture the G1 and "roll it out" that would be great, but it has to be constructed in place. And here lies the problem. Constructing a G1 in a wet area is highly problematical and time consuming. It can certainly not be constructed "fast track", and this is where a lot of people (and contractors) burn their fingers. For example, whilst constructing the South Coast Toll there was a bonus payment offer to the contractor to complete the works prior to onset of Christmas holidays (earlier income of toll in peak traffic season). In 1 month (November) there was 23 days extension of time due to inclement weather. The G1 would not dry out sufficiently to permit surfacing. In addition to rain, the high humidity also extends the period before you can surface. We are now living with the consequences of localised premature failures as the layer was obviously still too moist when the asphalt surfacing was applied, which resulted in micro cracking during construction which only manifest themselves years later (you cannot test every square metre at the time). This is never brought into the equation. My experience is that, in ideal conditions, from commencement of constructing a section, it is at least a week before the surfacing can be applied, (keeping in mind the "time is money"). Also, applying a "stiff" asphalt AC surfacing on a G1 in a wet environment is fraught with risk of early cracking in asphalt, followed by ingress of moisture. A surface seal as a 1st surfacing is thus preferable, followed by asphalt a couple of years later, when the whole pavement has settled down. This must therefore be planned for.

Further, if a G1 is constructed for heavy traffic in a wet area, then the pavement cross-section takes on more important criteria. Often, climbing lanes are marked out on our existing standard X sections which means that there is little or no surfaced shoulder. G1 bases are far more susceptible to ingress of moisture from the side than asphalt bases. This must therefore also be taken into account when selecting a base type, especially in wet areas. Sorry to ramble on about this, but to my knowledge, the problems mentioned above do not appear in any publication that I know of.

Performance predictions, (and thus recommendations), although based on sound research outcomes, should thus always be accompanied by constructability restraints to prevent the repeat of issues such as the above occurring time after time.

- **For Crushed Stone layers on cemented subbases, the damage equivalency exponent “n” was proven to be lower than 4.2, and closer to 3 (on average)**

Before the HVS investigations on G1 base pavements were completed, the exponent used to convert traffic loads to equivalent standard axles (E80's) was 4.2, as suggested by the AASHTO road test. The HVS tests showed that the equivalency exponent was dependent on pavement condition (especially moisture) and load magnitude and could range from 1 to 5 for G1 base pavements, with an average value of around 3. For the same traffic spectrum, the use of a lower equivalency factor results in a reduced design traffic. This means that, with the use of a reduced equivalency factor, many roads with G1 bases could be designed for a lower traffic class.

The relative contribution of HVS investigations to this impact is estimated to be around 80 per cent. This contribution is again based on the accelerated and precise nature of HVS testing and information gathering. Without the benefit of precisely controlled loads and knowledge of applied number of repetitions, the evaluation of the equivalency exponent would have required many years of costly performance data gathering.

Mr. Rossmann's Comments:

I agree with the valuable input from HVS on this issue. May I however suggest that you rephrase the above. It took me some time to understand the above statements (not however difficult to confuse me!) as you are saying something in “reverse”. In essence what you are saying is that the G1 pavement in the original thinking could be raised by 1 traffic class?

- **The design methodology for Crushed Stone layers, coupled with the validation through HVS investigations, showed that a thickness of 150 mm is optimal for G1 layers.**

Prior to the HVS investigations on G1 base pavements, there was a tendency to use thicker Crushed Stone layers for higher traffic demands. This approach stemmed from the AASHTO methodology which largely strove to protect the subgrade through the use of a thicker pavement structure.

The development of the “Safety Factor” method for designing Crushed Stone layers, and its subsequent validation through HVS testing, provided proof that thicker Crushed Stone layers could be more prone to failure, owing to the reduction in the compressive stress needed to induce high shear strength in such materials. The resulting optimization of layer thickness has obvious economic impacts.

The relative contribution of HVS investigations to this impact is estimated to be around 30 per cent. This contribution is based on fact that the optimization of G1 layer thickness was largely based on analytical evaluations of Maree (1982). However, the HVS investigation contributed by validating the theory and by providing data to refine the design methodology for Crushed Stone layers in South Africa.

Mr. Rossmann's Comments:

I agree. However, sometime in the early 90's someone came up with the idea that 125mm G1 was just as good (possibly from HVS data) for the predicted traffic design class. This has proved to be a disaster and we are now paying for it. On the N1 south Toll road the original concessionaire constructed the pavement with a 125 mm G1 in 1988. We are finding that areas we now have to reconstruct have G1 thicknesses down to 100 mm in places. One can only assume that this was as a result of poor level control during construction. Recommendations based on research must thus always take into account construction limitations and achievable tolerances (we know that the skills of current grader operators are not what they used to be).

- **The difference between the performance of a high density (G1 class) base and a lower density (G2 class) base was clearly proven**

Before the findings of the HVS tests on G1 base pavements were published, there was a theory - prevalent amongst some researchers - that a more open graded granular layer is less sensitive to moisture. The HVS tests on G1 and G2 materials conclusively showed that a higher density Crushed Stone is less sensitive to moisture and provides better protection against moisture for the other pavement layers. This finding contributed to refine specifications and construction methods for G1 materials.

The relative contribution of HVS investigations to this impact is estimated to be around 40 per cent. This contribution is based on fact that the HVS tests were instrumental in proving the difference between the high quality, high density G1 material, and the lower density G2 materials. However, the assigned contribution also recognizes other contributions stemming from the experiences of the National Department of Transport and provincial administrations in the development and refinement of specifications for G1 materials.

Mr. Rossmann's Comments:

The HVS certainly highlighted the benefits of maximizing compaction levels. This whole question of compaction levels is still very much an issue in the industry. People have forgotten the benefits of maximizing compaction. I get involved on numerous occasions where the contractor says he cannot get the required compaction. It's been sorted out by varying the technique and not trying to fast track the process. Water absorption of the aggregate is often blamed, as well the formulae for Apparent Density. In fact there are a number of countries north of our borders that no longer construct G1 type bases as they have had bad experiences with them. The feeling there is that weathered bases perform better, which of course is nonsense. The major problem there has been that they construct G1's the same as say G4, with disastrous consequences due to compaction not having been maximized (low C and Ø).

We have/are experiencing some problems whereby G2 material was blended with gravel. The weathered dolerite used has further weathered in service and now has PI values up to 12, which makes it very sensitive to moisture.

Additional Notes or Comments:

There is no question that HVS has assisted greatly in development and performance prediction of G1/G2 bases. As you say however, the % contribution is the subjective one, so I will go along with your numbers.

Unfortunately a lot of peripheral (but no less important) issues, such as pavement cross-section, climate, constructability and tolerances have been (and unfortunately are still being) lost, and do not form part of the selection equation of the new practitioner. There should be a lot more emphases on “caveats” in HVS findings (Reports). While often the results of HVS testing are sound and useful, they are taken out of context with respect to the above additional issues, with dire consequences (I see it often).

Further Example:

There has been some good HVS work on Foam bitumen. We know a lot more of the predicted behaviour of the base itself than we did before. But what about the surfacing to go on top? Obviously an asphalt surfacing would work, but this is expensive and sometimes impractical. However how soon will a seal punch into the foamed base (lower compaction levels than G1)? A lot more benefit could accrue if appropriate surfacings were evaluated at the same time as testing the base. (e.g. if only an asphalt is suitable then this would have to be brought into the equation up front, which may not make the foaming option cost effective anymore). These are the type of issues facing practitioners.

Record of Interview

Interview With: **Mr. Gawie Jordaan (GJ)**

Interview Date: 4 June, 2004

Interview Duration: Approximately 30 minutes

Context: Mr. Jordaan is an experienced pavement practitioner currently working with Trans African Concessions, and was formerly associated with BKS Consulting and the National Department of Transport. Mr Jordaan has extensive experience of pavement design and construction and has been influential in the development and implementation of pavement design and construction technology in South Africa.

Details of interview

General / Background:

- A problem statement was discussed and the need for quantifying research benefits was provided.

Acceptance of G1 for 12 to 50 MISA

- GJ agrees with this impact, and also with the 80 per cent contribution suggested for the HVS investigations.
- GJ noted that he was aware of specific roads on which the original design favoured an asphalt or concrete base. The most notable of these is the N1 between Warmbaths and Pietersburg. GJ noted that, in his former role as engineer at the Department of Transport, he performed a concept design for this road. The original design, performed in the late 1970's and early 1980's, was a concrete road. According to GJ, the G1 base pavements were at that stage not held in high regard by many practitioners, and at that stage, concrete proved to be most economical. The design for this road was later re-evaluated and re-designed as a G1 base pavement, between Warmbaths and Pietersburg. This re-evaluation was affected by the dissemination of G1 technology during the early 1980's, when the HVS tests on G1 materials were performed.

The Suitability of G1 for Wet Climate Zones

- GJ agrees with this impact, and also with the contribution ratio of 80 per cent.

The Use of an n-Value of Less Than 4.0 for G1 Base Pavements

- GJ agrees with this impact, and with the allocated contribution ratio of 80 per cent.

The use of 150 mm G1 instead of 200 mm

- GJ noted that there was a tendency for earlier designs to use thicker Crushed Stone layers for higher traffic demands (example is the Alberton to Heidelberg road).
- GJ agrees with this impact and also with the suggested 30 per cent contribution ratio.

The Difference between G1 and G2 Materials

- GJ agrees with this impact, but feels the contribution of HVS investigations specifically is somewhat lower (around 30 per cent).

- GJ noted that, because of this impact, some specifications for G1 materials were actually changed, notably those of the Cape Provincial Administration.

Other Benefits / Process Benefits / General Issues

- GJ agrees that the HVS investigations definitely assisted greatly in the development of South African pavement design technology. However, as a member of the HVS Steering Committee in earlier years, GJ felt that at times not enough attention was paid to materials design and specification aspects.

APPENDIX E

ANALYSIS OF THE IMPACT OF IMPROVED MAINTENANCE AND CONSTRUCTION PRACTICES

Introduction

In this Appendix, the economic impact of improved maintenance and construction practices on pavements with unbound base layers is evaluated. The analysis evaluates the life cycle costs of several pavement performance alternatives, which are presumed to be the effect of either good or poor maintenance and construction practices.

The objective of this analysis is to obtain a relative evaluation of the economic benefits associated with the following broad impacts that were realized through HVS testing on G1 base pavements:

- The HVS investigations greatly enhanced the understanding of the pavement as a system, and showed the importance of timely maintenance (specifically the maintenance of an impervious surfacing) on pavements with unbound base layers.
- The HVS investigations showed clearly the difference between a high quality, high density Crushed Stone base (type G1, or G1a) and a lesser quality, less dense Crushed Stone (G2 or G1b). The investigations highlighted the importance of proper compaction, specifically to limit the impact of water ingress into the layer.

Analysis Assumptions

For this analysis, three different pavement performance scenarios were evaluated. In general terms, these scenarios are:

Scenario 1: Typical G1 Base Pavement Performance

This scenario is considered to be the reference case scenario, and is based on the typical G1 base pavement performance as documented in Appendix B.

Scenario 2: Delayed Maintenance Causing Earlier Rehabilitation

This scenario represents a case where the maintenance of an impervious surfacing is delayed, with the result that the unbound base rapidly deteriorates when water enters into the layer. The result is earlier structural rehabilitation.

Scenario 3: Poor Compaction and Material Specifications during Construction

This scenario represents a case where the material used during construction is not of the quality required for G1 materials. More importantly, it assumes a case where the base is not properly compacted. The assumed consequence is early structural rehabilitation owing to deformation in the base and disintegration of the surfacing.

Details of the assumed performance life cycles of the three assumed scenarios are summarized in Table E1. The design life for all scenarios is assumed to be 25 years. Except for forced interventions, the period between maintenance and rehabilitation actions was assumed to be between 9 and 11 years for all three scenarios.

Table E1: Life Cycle Events for Three Assumed Scenarios

Scenario	Year of Intervention	Intervention Description
Proper Maintenance and Construction	0	Initial Construction with proper compaction and right specifications
	10	Maintenance: New Surface Seal
	20	Structural Rehabilitation: Rework base and treat with emulsion and/or cement.
Delayed Maintenance of Surfacing	0	Initial Construction with proper compaction and right specifications
	10	<u>None</u> (New Surface Seal is delayed)
	14	Structural Rehabilitation required owing to deformation in base and cracking of surfacing. Rework base and treat with emulsion and/or cement.
	24	Maintenance: New Surface Seal
Delayed Maintenance of Surfacing	0	Initial Construction <u>with poor compaction</u> and incorrect material specifications
	6	Early Structural Rehabilitation required owing to deformation in base, cracked surfacing and high moisture content in upper layers. Rework base and treat with emulsion and/or cement.
	15	Maintenance: New Surface Seal
	24	Maintenance: New Surface Seal

The pavement structure was assumed to be a typical G1 base over cemented subbase, roughly suitable to accommodate between 12 and 30 million standard axles (MISA). The pavement structure was assumed to consist of:

- 40 mm Continuously Graded Asphalt;
- 150 mm Crushed Stone base (G1);
- 250 mm Cemented subbase (C3), and
- 150 mm Selected Material (G7).

Material costs were based on those reported by Walker and Freeme (1985) (see Appendix B for details), and the life cycle cost is thus in terms of 1985 Rand. The life cycle cost calculations for the three scenarios are shown in Figures E1 to E3, and are summarized in Table E2. The savings that can be achieved if Scenario 1 is realized instead of Scenarios 2 or 3 are summarized in Table E3.

Table E2: Summary of Life Cycle Cost for Three Assumed Scenarios

Scenario	Life Cycle Cost per Square Metre, at a Discount Rate of:		
	4%	8%	12%
Scenario 1: Base Case	R 23.88	R 18.97	R 16.65
Scenario 2: Delayed Maintenance	R 25.76	R 20.91	R 18.19
Scenario 3: Poor Construction	R 30.63	R 26.88	R 24.20

Year	Base Year (Year 0)		
Situation	Initial Construction		
Structure & Cost	40 mm Asphalt Surfacing	R 7.00	
	150 mm Granular Base	R 4.20	
	250 mm Cemented Subbase	R 2.50	
	150 mm G7 Selected Layer	R 0.50	
Cost Calculation	Total Cost per square metre	R 14.20	
	Discount Period	0	
	PWOC at discount rate of 4%	R 14.20	
	PWOC at discount rate of 8%	R 14.20	
		PWOC at discount rate of 12%	R 14.20
Year	Year 10		
Situation	First Surface Seal (Maintenance)		
Treatment	Single Seal	R 1.50	
Existing Structure	40 mm Asphalt Surfacing	R -	
	150 mm Granular Base	R -	
	350 mm Cemented Subbase	R -	
	150 mm G7 Selected Layer	R -	
Cost Calculation	Total Cost per square metre	R 1.50	
	Discount Period	10	
	PWOC at discount rate of 4%	R 1.01	
	PWOC at discount rate of 8%	R 0.69	
		PWOC at discount rate of 12%	R 0.48
Year	Year 20		
Situation	Structural Rehabilitation		
Treatment	40 mm Asphalt Surfacing	R 7.00	
	Rework and Treat Base as ETB	R 12.00	
Existing Structure	40 mm Asphalt Surfacing	R -	
	150 mm Granular Base	R -	
	350 mm Cemented Subbase	R -	
	150 mm G7 Selected Layer	R -	
Cost Calculation	Total Cost per square metre	R 19.00	
	Discount Period	20	
	PWOC at discount rate of 4%	R 8.67	
	PWOC at discount rate of 8%	R 4.08	
		PWOC at discount rate of 12%	R 1.97
Total PWOC at Discount Rate of 4% =		R 23.88	
Total PWOC at Discount Rate of 8% =		R 18.97	
Total PWOC at Discount Rate of 12% =		R 16.65	
Note: All costs shown are per square metre			

Figure E1: Life Cycle Cost Evaluation for Scenario 1 (Base Case)

Year	Base Year (Year 0)	
Situation	Initial Construction	
Structure & Cost	40 mm Asphalt Surfacing	R 7.00
	150 mm Granular Base	R 4.20
	250 mm Cemented Subbase	R 2.50
	150 mm G7 Selected Layer	R 0.50
Cost Calculation	Total Cost per square metre	R 14.20
	Discount Period	0
	PWOC at discount rate of 4%	R 14.20
	PWOC at discount rate of 8%	R 14.20
	PWOC at discount rate of 12%	R 14.20

Year	Year 14	
Situation	Structural Rehabilitation	
Treatment	40 mm Asphalt Surfacing	R 7.00
	Rework and Treat Base as ETB	R 12.00
Existing Structure	40 mm Asphalt Surfacing	R -
	150 mm Granular Base	R -
	350 mm Cemented Subbase	R -
	150 mm G7 Selected Layer	R -
Cost Calculation	Total Cost per square metre	R 19.00
	Discount Period	14
	PWOC at discount rate of 4%	R 10.97
	PWOC at discount rate of 8%	R 6.47
	PWOC at discount rate of 12%	R 3.89

Year	Year 24	
Situation	Surface Seal (Maintenance)	
Treatment	Single Seal	R 1.50
Existing Structure	40 mm Asphalt Surfacing	R -
	150 mm Granular Base	R -
	350 mm Cemented Subbase	R -
	150 mm G7 Selected Layer	R -
Cost Calculation	Total Cost per square metre	R 1.50
	Discount Period	24
	PWOC at discount rate of 4%	R 0.59
	PWOC at discount rate of 8%	R 0.24
	PWOC at discount rate of 12%	R 0.10

Total PWOC at Discount Rate of 4% =	R 25.76
Total PWOC at Discount Rate of 8% =	R 20.91
Total PWOC at Discount Rate of 12% =	R 18.19
Note: All costs shown are per square metre	

Figure E2: Life Cycle Cost Evaluation for Scenario 2 (Delayed Maintenance)

Year	Base Year (Year 0)	
Situation	Initial Construction	
Structure & Cost	40 mm Asphalt Surfacing	R 7.00
	150 mm Granular Base	R 4.20
	250 mm Cemented Subbase	R 2.50
	150 mm G7 Selected Layer	R 0.50
Cost Calculation	Total Cost per square metre	R 14.20
	Discount Period	0
	PWOC at discount rate of 4%	R 14.20
	PWOC at discount rate of 8%	R 14.20
	PWOC at discount rate of 12%	R 14.20
Year	Year 6	
Situation	Structural Rehabilitation	
Treatment	40 mm Asphalt Surfacing	R 7.00
	Rework and Treat Base as ETB	R 12.00
Existing Structure	40 mm Asphalt Surfacing	R -
	150 mm Granular Base	R -
	350 mm Cemented Subbase	R -
	150 mm G7 Selected Layer	R -
Cost Calculation	Total Cost per square metre	R 19.00
	Discount Period	6
	PWOC at discount rate of 4%	R 15.02
	PWOC at discount rate of 8%	R 11.97
	PWOC at discount rate of 12%	R 9.63
Year	Year 15	
Situation	Surface Seal (Maintenance)	
Treatment	Single Seal	R 1.50
Existing Structure	40 mm Asphalt Surfacing	R -
	150 mm Granular Base	R -
	350 mm Cemented Subbase	R -
	150 mm G7 Selected Layer	R -
Cost Calculation	Total Cost per square metre	R 1.50
	Discount Period	15
	PWOC at discount rate of 4%	R 0.83
	PWOC at discount rate of 8%	R 0.47
	PWOC at discount rate of 12%	R 0.27
Year	Year 24	
Situation	Surface Seal (Maintenance)	
Treatment	Single Seal	R 1.50
Existing Structure	40 mm Asphalt Surfacing	R -
	150 mm Granular Base	R -
	350 mm Cemented Subbase	R -
	150 mm G7 Selected Layer	R -
Cost Calculation	Total Cost per square metre	R 1.50
	Discount Period	24
	PWOC at discount rate of 4%	R 0.59
	PWOC at discount rate of 8%	R 0.24
	PWOC at discount rate of 12%	R 0.10
Total PWOC at Discount Rate of 4% =		R 30.63
Total PWOC at Discount Rate of 8% =		R 26.88
Total PWOC at Discount Rate of 12% =		R 24.20
Note: All costs shown are per square metre		

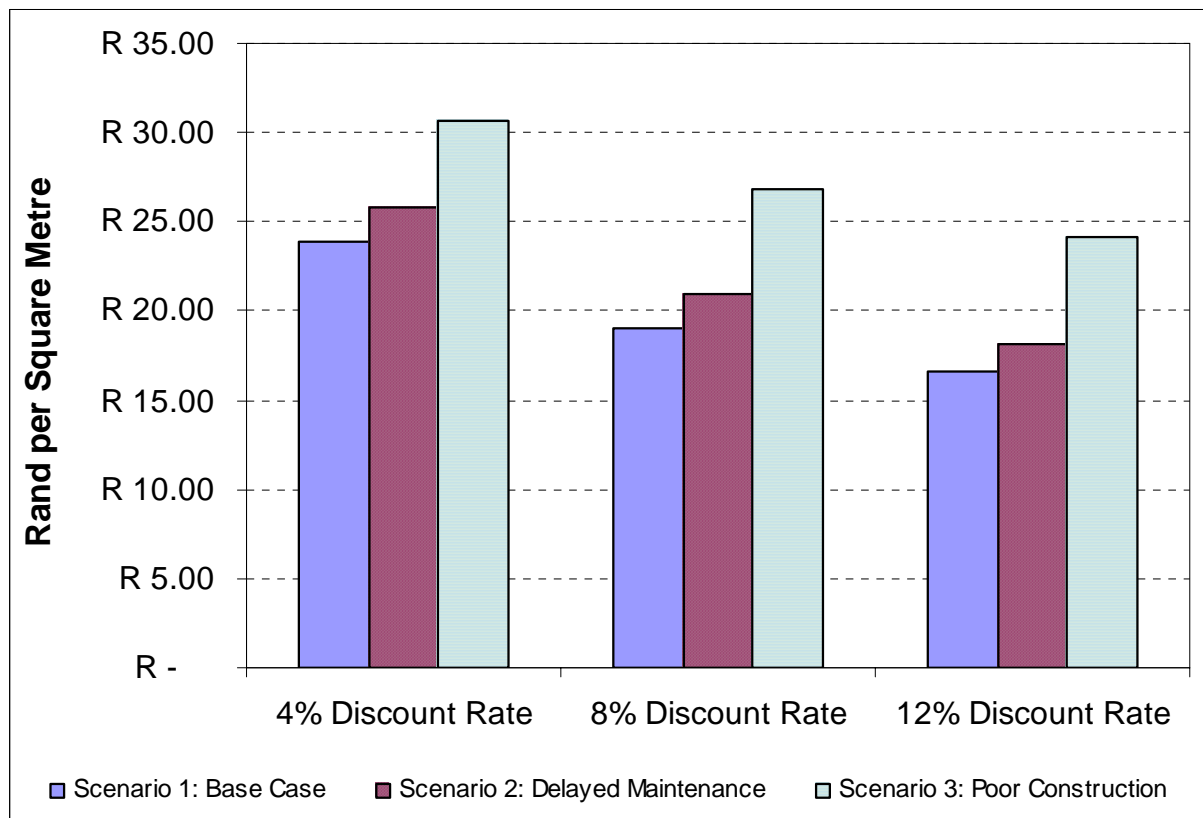
Figure E2: Life Cycle Cost Evaluation for Scenario 3 (Poor Construction and Specifications)

Table E3: Summary of Life Cycle Cost Savings

Scenario	Life Cycle Cost Savings per Square Metre, Relative to Scenario 1, at a Discount Rate of:		
	4%	8%	12%
Scenario 1: Base Case	R -	R -	R -
Scenario 2: Delayed Maintenance	R 1.87	R 1.93	R 1.53
Scenario 3: Poor Construction	R 6.75	R 7.91	R 7.55

It should be noted that the savings shown in Table E3 are those which would be directly realized by a road owner such as Gautrans, if proper maintenance and construction practices are applied over the long term on a provincial or national network. Road user costs such as those incurred because of a greater number of interventions (e.g. Scenario 3 requires one additional intervention in a 25 year period) are not included in these savings.

Actual road user costs are difficult to determine, since it requires quantification of aspects such as the cost of an accident, the percentage increase in accidents during road works, time delay cost due to traffic congestion during road works, etc. A study by Gillen et al (2000), suggest that, for conditions in the United States, the road user cost element is typically greater than the direct agency savings. Thus the life cycle cost savings shown in Table E3 is a significant underestimate of total cost savings. It is, however, a reasonable estimate of direct agency cost savings.

**Figure E4: Summary of Life Cycle Cost for Different Scenarios and Discount Rates**