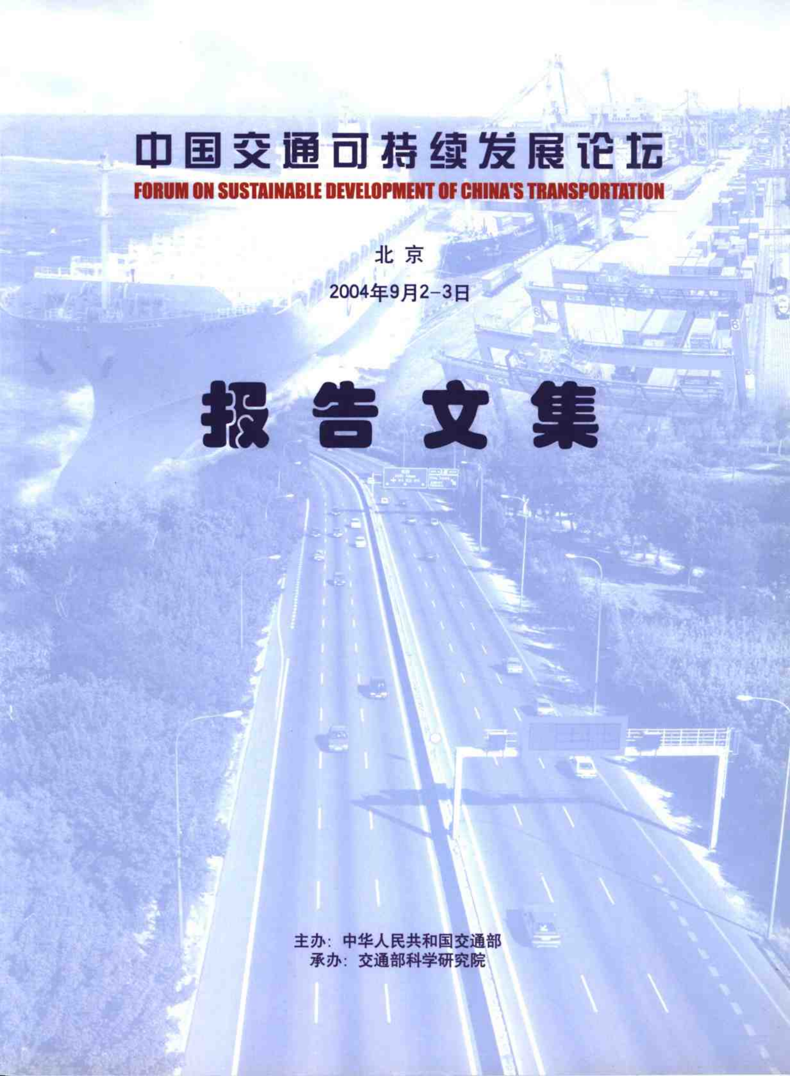

中国交通可持续发展论坛

FORUM ON SUSTAINABLE DEVELOPMENT OF CHINA'S TRANSPORTATION

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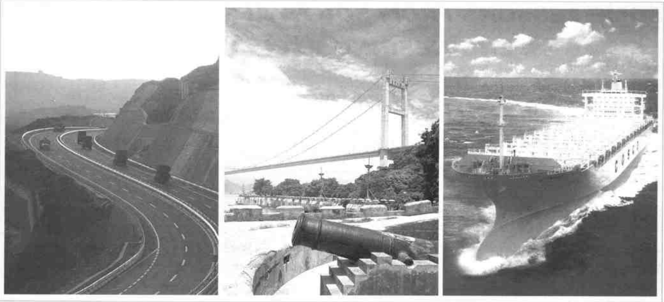


中国交通可持续发展论坛

FORUM ON SUSTAIN ABLE DEVELOPMENT OF CHINA' S TRAN SPORTATION

目录

SOME LESSONS FROM SOUTH AFRICAN PAVEMENT ENGINEERING EXPERIENCE

to be presented at the
Asphalt Pavement Technology Conference
Beijing - September 2004

BY

PROF FRED HUGO PE Fellow SAAE

ABSTRACT

As a developing country South Africa has an extensive network of high standard highways that have performed well over the past twenty five years. The cost-effective quality of the pavements has been demonstrated by the manner in which the system has coped with the high growth rate in heavy truck traffic during the past ten years due to deregulation of freight transport.

The structural designs are based on the extensive accelerated pavement test programme (APT programme) that extends back to the seventies of the previous century. However, it has to be stressed that the success of the structural designs is due to the integrated nature of the design system. The components comprise materials knowledge supported by sound engineering geology, good construction and appreciation of the environmental impact, to name only some of the underpinning elements. These South African structural designs have also been considered lean by comparison to some used for comparable traffic in other parts of the world.

The system is coming more and more under pressure due to an increase in loading (legal and illegal). Another compounding factor is the lack of sufficient funding to take the necessary steps timely to ensure proper maintenance before irreversible damage is done. New technologies have been developed to gain a better understanding of the factors that impact on performance and mechanisms of distress. These include monitoring of contact stresses and an improved mechanistic-empirical design method.

The paper will present an overview of some aspects of the system that may be useful to Chinese road authorities and pavement engineers. One such aspect is the inverted pavement structure that has been widely used in South Africa. The strategy behind this system will be discussed together with guidelines on aspects that are of importance to ensure success with the utilization of the strategy.

Keywords: cement stabilization, pavement structure, accelerated pavement tests (APT), mechanistic-empirical design

INTRODUCTION

The South African road network is currently under heavy pressure due to the economy and the enormous growth in heavy vehicles (trucks) apart from overloading. This is exacerbated by the increased legal axle loads that were approved in 1996. The effect of this can be seen in the following brief graphic overview of statistics presented in Table 1 and Figures 1 through 5.

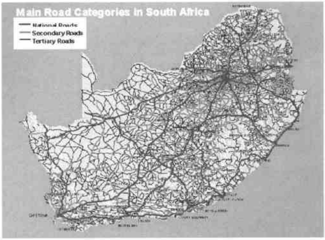


Table 1 Statistics of the South African Road Network

South African Road Network	
Description	**Total Length (km)**
Dual Carriageway	2 032
4-Lane Divided	1 094
2- Lane Single	60 027
2- Lane Gravel	300 978
Total Non-Urban Road Network	364 131
Estimated Urban Road Network	170 000
Total Road Network	535 000

Table 1 and Figure 1 present the statistics of the South African Road Network in tabular and graphic format. Figure 2 and 3 show how the road network has deteriorated over the past five years and what could happen if steps are not taken to curb this trend. Figure 2 presents the change in the National Road network and Figure 3 shows statistics pertaining to Gauteng, the province which is the economic hub of the country.

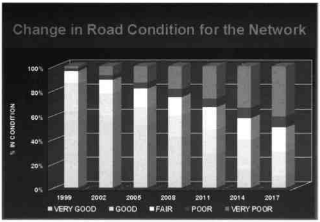


Figure 2 Change in Condition of the South African Road Network (after Nordengen 2002)

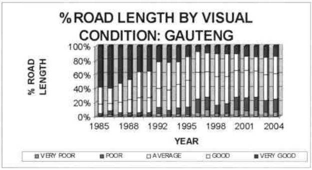


Figure 3 Change in Road Condition of Gauteng Province, So Africa over Ten Years

(Statistics provided by Gauteng Province, Department of Transport and Public Works)

Table 2 sets out the changes in the Legal Axle loads that were promulgated in 1996 and the expected increase in damage to the highways. This is a factor that needs to be borne in mind when considering the progressive deterioration in the road system together with the greatly reduced funding of maintenance. There are many examples of this in different types of pavements. It has also been exacerbated by overloading and excessive tyre pressures. The latter has been extensively researched in South Africa over the past decade among other by De Beer et al. (1997) and Groenendijk et al., (1997). They described the quantification of three-dimensional (3-D) tire/pavement contact stresses for vehicle tires using the Vehicle-Road Surface Pressure Transducer Array (VRSPTA) system (Figure 4). The most important finding was the large differences that were measured in contact stress under tyres. The fact that stresses could reach levels of 100 percent more than the inflation pressure has serious consequences for the upper layers in the pavement. This is particularly relevant when the base course is CSCR since it could affect the rate of crushing and deterioration of the layer surface. Another serious finding was the increased tyre pressures that were being measured in general. These two factors must be taken into consideration in designs of pavements.

Table 2 Effect of Increased Axle Loads in South Africa (after Nordengen 2002)

• Axle loads 8 200 to 9 000 kg
• 9.8 % increase in mass
• 48% increase in road damage (wear)
• Could be more than 75% on certain provincial roads

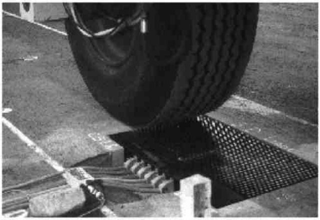


Figure 4 VRSPTA - a device for measuring the contact stress between tyre and road surface (after De Beer et al, 1997)

The pavement system experienced strong phases of development in the seventies and eighties of the previous century. In these phases the HVS program played a very important role. Expertise was built up in all aspects of pavement engineering including design, construction and research (Rust et al, 1997). This course of events proved to be sound investment when the economy of the country took a turn in the nineties and investment in new highway infrastructure and related maintenance of the system took a down-turn. When the slump set in, a number of factors caused truck traffic to start growing faster. A primary reason for this was the deregulation of freight transport causing a shift from rail to road.

The core of the success of the development of the pavements system is to a large extent, due to the integrated nature of the structural design system. The research findings from the accelerated pavement testing (APT) programme with the Heavy Vehicle Simulator (HVS) were rapidly implemented by close interaction between researchers, client bodies such as highway departments of transport, consultants and contractors.

Figure 5 A Unique Manifestation of "Accelerated" Pavement Distress due to Traffic on a Regional Road R103 (formerly N3) near Warden, South Africa.

SOME BACKGROUND TO THE SOUTH AFRICAN DESIGN GUIDE

More than twenty five years ago a paper on the SA mechanistic design guide was published (Walker et al, 1977). Following this, draft design guidelines [TRH4], were published (NITRR, 1978). Work continued in the early eighties with two major conference in South Africa on accelerated pavement testing (APT) in 1984 and 1985 respectively. Freeme (1984) and Walker (1985) presented excellent overviews of aspects of the SA-HVS research. Revised draft design guidelines [TRH4], (NITRR, 1985) were published at the same time.

Knowledge continued to develop particularly in the fields of engineering geology, materials and structural analysis. One of the pillar stones of this process was the understanding of the interaction between materials and structures. The factors that influence performance such as fatigue and deformation of materials became known through sound research, good construction and an appreciation of the environmental impact, to name only some of the underpinning elements. Otte (1977) completed extensive research on the use of chemically stabilized materials and much of this found its way into practice. De Beer followed this up in the nineties, looking at the impact of crushing of the surface of stabilized layers.

In 1996 details of the updated South African Mechanistic Design Method, was presented by Theyse et al., (1996). This mechanistic- empirical design method includes fatigue transfer functions for asphalt surfacing, asphalt base, and lightly cemented layers, as well as permanent deformation transfer functions for unbound structural layers and the roadbed. All of these were developed through the SA-HVS program. The method is based on a critical layer approach whereby the shortest layer life of the individual pavement layers determines the pavement life. Although this approach is suited to the fatigue failure of bound layers, it does not allow for each of the pavement layers to contribute to the total surface rut. Current research is underway to enable the designer to predict each layer's contribution to the total permanent deformation of the pavement system.

Transfer functions were modified to include reliability for different traffic levels. Table 2 (after Theyse et al '96) shows the characteristics of the materials that form the basis of the latest mechanistic-empirical design procedures. Elastic-layered analysis was used to determine the response of the pavement structures, but more sophisticated analytical tools such as finite elements and visco-elastic and elasto-plastic analyses are now being utilized to improve the method. Much of this has been documented and presented world-wide. The recently completed synthesis of significant findings from full-scale APT bears witness to this (Hugo and Epps Martin, 2004). Figure 6 from this synthesis shows how many factors are involved in a pavement engineering system. Of course the end gaol is to produce pavements that perform well and are at the same time economical.

The South African structural designs have been considered

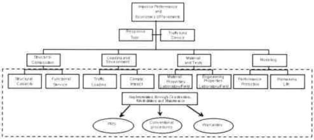


Figure 6 Framework for Exploring Knowledge Generated by APT Programs[after Figure A1 in Hugo and Epps Martin, (2004)]

lean by comparison to some used for comparable traffic in other parts of the world. Some of this is due to a favourable climate in parts of the country, but of particular importance is an understanding of the mechanisms of distress in pavements. This paper will cover aspects of the design process, and give some insight into factors of importance in understanding some of the issues that pavement engineers face in achieving desired performance and economic pavements.

Figure 7 A Comparison of Typical Nominal Pavement Structures in South Africa and California (after Nordengen 2002)

THE CURRENT SOUTH AFRICAN MECHANISTIC-EMPIRICAL DESIGN METHOD (SMDM)

I shall briefly cover the salient features of the SMDM that was eloquently outlined in the paper by Theyse et al, (1996) that was mentioned earlier. It forms the basis of the latest TRH4 for design of road pavements in South Africa (SANRAL, 1996).

The following primary elements govern performance of pavements in a road system:

- Load characterisation
- Pavement characterisation
- Structural analysis
- Transfer functions
- Pavement bearing capacity estimation

Table 3 shows the Road Categories used in TRH 4

Table 3 Road Categories

Road Category	Description	Approximate design reliability (%)
A	Interurban freeways and mayor roads	95
B	Interurban collectors and mayor rural roads	90
C	Rural roads	80
D	Lightly trafficked rural roads	50

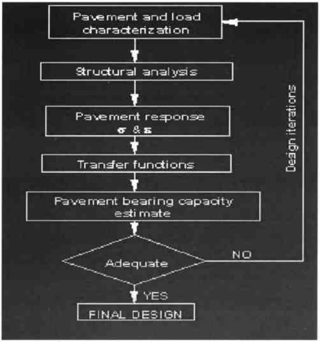


Figure 8. A Schematic Flow Diagram of Steps in the Pavement Design System

As was pointed out above, the load characterization (See Table 4) that has been operational over the past forty years was recently drastically affected when the legal axle load was changed in 1996. The effect of this has been taken into account in the latest revision of the South African design guide (SANRAL, 1996). However, the tyre pressures are still at an unrealistic level compared to what has been measured in the field.

Table 4 TRH4 '96 load characterization

• 88 kN legal axle load (1996)
• 80 kN design axle load
• 40 kN dual wheel design load
• 520 kPa uniform contact pressure

Pavement characterisation

Primary input parameters of the SMDM are:

- C Material parameters
- C System geometry

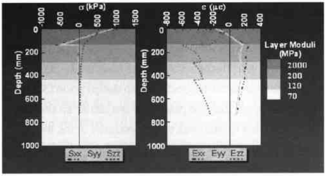
The materials in the South African design system relate to the physical and chemical characteristics. However, unlike most systems in the world that define the materials relative to the composition and aspects such as grading, plasticity etc, South Africa has added the response to stress and the resulting deformation characteristics as primary elements i.e. the strength characteristics. Table 4 gives an overview of the material that is considered in the TRH 4 design catalogue (SANRAL, 1996).

The structural layer geometry has been standardized to enhance constructability. In addition the layer composition has been selected to optimize in terms of performance and economy. The discussion of these structures will be limited to those cases that are related to the scope of the presentation.

Structural analysis

The SMDM utilized both elastic and elasto-plastic structural analyses for its analyses. The basic analysis, is a static, linear elastic multi-layer analysis with pavement response, in terms of stresses and strains. Typical examples are shown in Figures 9a and 9b. The respective elastic moduli for the materials for input in the analysis have been determined over time for the different pavement conditions and recommended values are reported by Theyse et al (1997).

Critical response parameters depend on material type and failure modes. These are as follows for the respective layers (Theyse et al., 1996):



Figures 9 (a) and (b) Examples of Typical stress/strain curves for cemented granular structure.

Performance evaluation and prediction

In terms of pavement performance, two approaches may

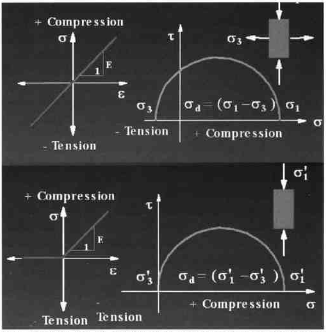
• Asphalt, ?h at bottom of layer	
	• Fatigue cracking
• Granular, Factor of Safety at mid-depth of layer	
	• Shear deformation
	• Permanent deformation
• Cemented ?h and??v at bottom and top of layer	
	• Effective fatigue
	• Crushing failure
• Subgrade ?v on top of layer	
	• Permanent deformation

be used. One includes the individual layer life, the other looks at the system holistically. In this manner it can be anticipated where the failure is likely to occur.

The performance of granular layers such as the G1 base etc, is measured in terms of Safety Factor F where F is defined by:

$$F = \frac{\sigma_3 \phi\text{-term} + c\text{-term}}{(\sigma_1 - \sigma_3)}$$

With some relative stiffnesses between the base and the subgrade, linear elastic analysis yields a tensile stress in the unbound material. This is as a result of using the same stiffness for tension and compression. If the layer were anisotropic, as it may well be, it would be possible to resist tensile stresses. However, the linear elastic analysis cannot handle this. To overcome this in a more fundamental



Figures 10 (a), (b), (c) and (d). Schematic procedure for overcoming calculated tensile stresses in the unbound base.

manner, Finite Element analysis (FEA) has to be utilized. The analytical dilemma is overcome by adapting the linear-elastic analysis. Tensile forces in the Mohr diagram are artificially made zero and the major principal stress is

Table 5 So African Road-Building Materials/ Material Codes (Theyse et al., 1996)

SYMBOL	CODE	MATERIAL	ABBREVIATED SPECIFICATIONS
	G1	Graded crushed stone	Dense - graded un weathered crushed stone ; Max size 37,5 mm; 88% apparent relative density; fines PI<4.0 (min 6 test)
	G2	Graded crushed stone	Dense - graded crushed stone ; Max size 37.5 mm; 100-120% mod.AASHTO or 85% bulk relative density: fines PI < 6 (min 6 tests)
	G3	Graded crushed stone	Dense - graded stone and soil binder ; max size 37.5 mm, 98-100% mod. AASHTO ; fines PI < 6
	G4	Natural gravel	CBR * < 80 ; max size 53 mm ; 98-100% mod.AASHTO ; PI <6 Swell 0,2 @ 100% mod.AASHTO
	G5	Natural gravel	CBR * < 45 ; max size 63 mm; or 2/3 layer thickness, density as described layer of usage; PI < 10 Swell 0,5 @ 100% mod.AASHTO
	G6	Natural gravel	CBR * < 25 ; max size 63 mm; or 2/3 layer thickness, density as described layer of usage; PI < 12 Swell 1,0 @ 100% mod.AASHTO
	G7	Gravel-soil	CBR * < 15 ; max size 2/3 layer thickness, density as described layer of usage; PI < 12 or 2GM + 10 ; Swell 1,5 @ 100% mod.AASHTO
	G8	Gravel-soil	CBR < 10 ; at insitu density ; max size 2/3 layer thickness, density as described layer of usage; PI < 12 or 2GM + 10 ; Swell 1,5 @ 100% mod.AASHTO
	G9	Gravel-soil	CBR < 7 ; at insitu density ; max size 2/3 layer thickness, density as described layer of usage; PI < 12 or 2GM + 10 ; Swell 1,5 @ 100% mod.AASHTO
	G10	Gravel-soil	CBR < 3 ; at insitu density ; max size 2/3 layer thickness, density as described layer of usage; or 90% mod.AASHTO
	C1	Cemented crushed stone or gravel	UCS 6 to 12 MPa at 100 % mod AASHTO; spec. at least G2 before treatment; dense - graded
	C2	Cemented crushed stone or gravel	UCS 3 to 6 MPa at 1 00 % mod. AASHTO; spec. generally G2 or G4 before treatment; dense - graded
	C3	Cemented natural gravel	UCS 1,5 to 3,0 MPa and ITS >250 kPa at 100 % mod. AASHTO; max. size 63 mm; lines Pi < 6 after stabilization.
	C4	Cemented natural gravel	UCS 0,75 to 1,5 MPa and ITS > 200 kPa at 100 % mod. AASHTO; max. size 63 mm; lines Pi < after stabilization.
	EBM	Bitumen Emulsion Modified gravel	0,6% - 1,5% residual bitumen
	EBS	Bitumen Emulsion Stabilised gravel	1,5% - 5,0% residual bitumen
	BC1	Hot - mix asphalt	Continuously -graded; max. size 53 mm
	BC2	Hot - mix asphalt	Continuously - graded; max size 37,5 mm
	BC3	Hot - mix asphalt	Continuously - graded; max. size 26,5 mm
	BS	Hot - mix asphalt	Semi - gap - graded; max. size 37,5 mm
Table 5 So African Road-Building Materials/ Material Codes (continued)			
	PCC	Portland cement Concrete	Modulus of rupture < 4,5 MPa; max size > 75 mm
	AG	Asphalt surfacing	Gap graded
	AC	Asphalt surfacing	Continuously graded
	AS	Asphalt surfacing	Semi-gap graded
	AO	Asphalt surfacing	Open graded
	AP	Asphalt surfacing	Porous (Drainage) Asphalt
	S1	Surface seal	Single seal
	S2	Surface seal	Multiple seal
	S3	Surface seal	Sand seal
	S4	Surface seal	Cape seal
	S5	Slurry	Fine grading
	S6	Slurry	Medium grading
	S7	Slurry	Coarse grading
	S8	Surface renewal	Rejuvenator
	S9	Surface renewal	Diluted emulsion
	WM1	Waterbound macadam	Max. size 75 mm, Pi of fines > 6, 88-90% of apparent density
	WM2	Waterbound macadam	Max. size 75 mm, Pi of fines > 6, 86-68% of apparent density
	PM	Penetration macadam	Coarse stone + keystone + bitumen
	DR	Dumprock	Upgraded waste rock, max size 2/3 layer thickness

UCS : Unconfined Compressive Strength; ITS : Indirect Tensile Strength;
CBR* at field compaction density; GM: Grading Modulus

adjusted while maintaining the deviator stress constant [schematically shown in Figures 9(a), (b), (c) and (d)].

Modes for Analysis of Cemented Layered structures.

Cemented materials generally suffer three forms of distress:

1. Fatigue
2. Crushing
3. Erosion due to pore pressure from water entering through shrinkage cracks

Critical control parameters are provided in the form of default values depending on material quality and layer thickness:

- strain at break ?t of CTB which
- maximum vertical ? v at the surface of the CTB

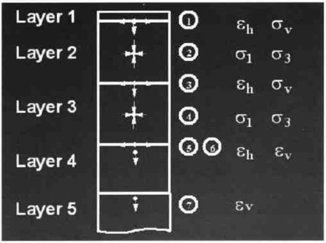
Two modes of distress are considered:

- Effective Fatigue = f(?h) (dependent on control parameters)
- Crushing

- Initiation = f(?v) = f(Contact Pressure)

- C Advanced = f(?v) = f(Contact Pressure)

The third mode needs to consider the range of distress mechanisms that are presented in Table 6, to determine the most appropriate method of dealing with the problem of erosion.



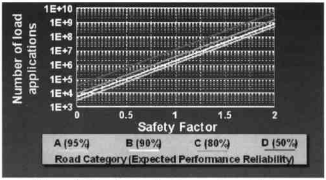
Figures 11 Schematic indicators of points that require analysis

Transfer functions

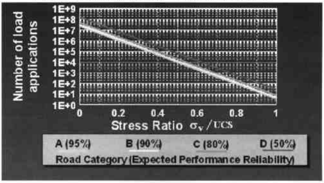
Transfer functions for the different materials comprise empirical data that has been built-up over time by interaction between APT research findings and in-service pavement performance. They relate to the following:

- Critical parameters that need to be considered
- Load repetitions
- Terminal condition that apply

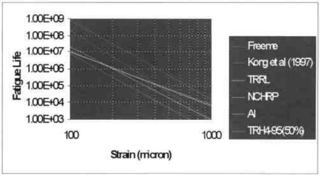
Figures 12-15 depict selected typical values that relate to SMDM graphically



Figures 12 Transfer function for granular material



Figures 13 Crushing life transfer functions for LCP(initiation)



Figures 14 Fatigue for thin continuously graded HMA (internationally)

PAVEMENT BEARING CAPACITY

In order to have a reference base for establishing and comparing pavement performance Pavement Bearing Capacity has been defined relative to layer life as the number of load repetitions to a specific level of permanent deformation. Layer life (bearing capacity) then enables one to determine which layers are critical in a pavement system and, this in turn serves as indicator as to how to correct the system or mitigate the negative effects

For reference purposes it should be noted that extensive details about the materials, structures, construction, rehabilitation and pavement management of South African pavements are contained in a series of reference documents. The following are particularly noteworthy:

- TRH3 Structural Design of Flexible Pavements for Interurban and Rural Roads, (SANRAL, 1996)
- TRH4 Structural Design of Flexible Pavements for Interurban and Rural Roads, (SANRAL, 1996)
- TRH12 Flexible Pavement Rehabilitation Investigation and Design (SANRAL, 1998)
- TRH14 Guidelines for Road Construction Materials (SANRAL, 1987)
- TRH 22 Pavement Management (SANRAL, 1994)

The influence of climate as well as traffic level is accounted for in the structural design of pavements. The various pavement structures naturally perform different depending upon the material characteristics and the possible distress mechanisms. I shall only focus on some selected cases which have had a major impact on South African pavement performance.

INVERTED PAVEMENT STRUCTURE

The inverted pavement structures, are now used extensively throughout South Africa. HVS testing has been instrumental in validating the effectiveness of these designs. The structures incorporate stabilized or lightly cemented (<4%) subbase layers that provide support to granular or asphaltic base layers. The stiffness of these stabilized subbase layers, while intact, are higher than that of the base layers. This allows adequate compaction of the base layer, and in the case of asphaltic base layers, reduces the development of horizontal tensile strains beneath the layer, hence extending the fatigue performance of the pavement structure. In the case of high-quality granular bases, the stiff subbase layer confines the base, and this "sandwich" effect has been shown to significantly increase the shear strength of high-quality granular bases. In the Synthesis 325 (Hugo and Epps Martin, 2004) a case study of such a pavement is reported which has performed very well and has already carried in excess of 14 million E80s over a period of 20 years. In that time a single surface preventative maintenance seal was applied. Rutting is nominally 6 mm.

CEMENT TREATED PAVEMENTS

Over the years pavements with cement treated layers have exhibited different performances depending on three factors, namely structural composition, load amplitude and environment.

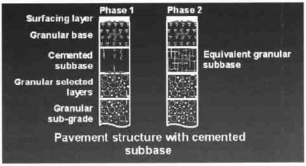
In South Africa the pavements with cemented subbases are generally integral parts of the inverted structures. Their success is dependent on the extent to which water can enter the upper layer system where it can result in pumping, erosion and structural distress. Good performance requires high density, unbound high quality stone base. The surface needs to be water tight and rainfall should preferably not occur fro prolonged periods. Many hundreds of kilometres of such pavements are in service in the Gauteng and neighbouring provinces.

Pavements with both the base and the subbase cement stabilized have also been successfully constructed but a number of factors have to be watched closely:

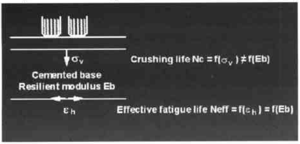
- Water entering the upper layers must be able to escape under pressure without damaging the CRCP and/or the asphalt surfacing.
- Carbonation can cause chemical distress to the CRCP layers

A particularly serious failure due to pumping and erosion occurred on a major freeway with a CSCR base during the early 1970s. Figures 25 (a) and (b) were taken on that section of highway. The layer had to be removed and was replaced with full-depth asphalt. The author was responsible for the rehabilitation work at the time. Failure was primarily due to pumping and erosion. No evidence of carbonation was detected. The road is still in service with some subsequent rehab work to strengthen the pavement to carry the increased traffic loading. Meng et al, (1999) also reported success with thick asphalt on a CTSB. In contrast Metcalf (1999) reported softening and erosion at the interface between CTSB and the thin asphalt surfacing.

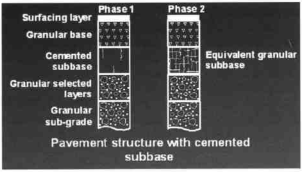
The performance of the pavements and related distress factors appear to be well understood from a research point of view. It is however imperative that pavement engineering practitioners understand the mechanisms clearly. Schematic details of the course of events that occur under wheel loading will help to clear up misconceptions and lead to better understanding of the course of events as trafficking progresses.



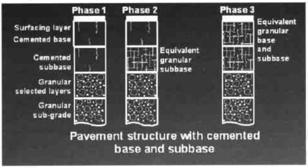
Figures 16. Modelling cemented material behaviour



Figures 17 Crushing of cemented base

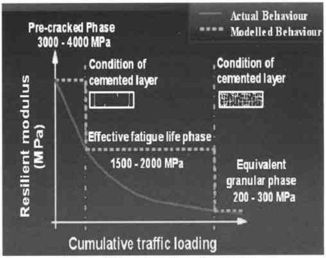


Figures 18 Pavement life phases with one layer LCP

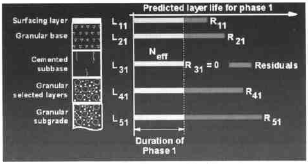


Figures 19. Two layers LCP three life phases

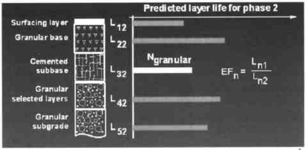
In essence the pavement structure and the stiffness of the respective layers changes progressively with time. It is this change that makes the layer vulnerable to pore pressure during trafficking. It is also important to pay attention to the response parameter ?b of the LCP layers. If cementiceous



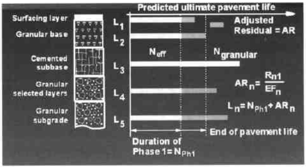
Figures 15 Long-term behaviour of LCP



Figures 20 Bearing capacity phase 1



Figures 21 Bearing capacity phase 2



Figures 22 Bearing capacity - Total

materials are used in blends, this is also important. If ?b is too small, the material is likely to crack easier.

The current method of establishing a critical layer has been found useful in determining the possibility of activating distress mechanisms as will be shown later. Transfer functions are by nature linkages between conditions of no initial distress and end condition of terminal distress. They are continuous even though they reflect upon materials that change during the life cycle. As such they are:

- Tools for estimating pavement bearing capacity during design stage
- Pavement management system takes over during the operational stage
- The basis for sound pavement design practice based on rational principles
- Tools for construction and quality control that can ensure that the design assumptions are satisfied

Currently the system is still focused upon critical layers. The ultimate approach is for determining total permanent deformation. This is still under development.

Figures 19 - 22 illustrate this course of events. It should be appreciated that the critical layer may change position in the structure in the course of time.

Typical inverted road structures

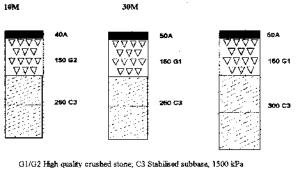


Figure 23 Three typical inverted pavement structures with different bearing capacities

Figure 23 graphically demonstrates how close various pavements lie in terms of the number of load applications that they can carry. PAVEMENT MATERIALS

Some comments on the influence of pavement materials on the performance of pavement structures need to be made. Generally the performance of asphalt layers is well understood however problems occur in composite pavements particularly were there is interaction between different layers and different materials. This is exacerbated with the interaction of water.

Apart from asphaltic materials there are in essence three factors of importance that I wish to discus:

- Quality of granular materials
- Level of compaction
- Nature and quality of stabilised materials

Materials are generally selected based on:

- Strength or load carrying capacity
- Strength/moisture/density
- Long term material durability

Relaxation, if it is to be considered, should be related to maintenance capability.

A discussion of details relating to materials is beyond the scope of the presentation. Suffice to say that factors such as the following needs to be considered:

Untreated materials

The following factors need to be considered in terms of pavement composition:

- Grading
- Atterberg limits (US PI not the same as BS PI)
- Bearing strength and swell
- Aggregate crushing strength and FI Index
- Deleterious materials - sulphides and soluble salts - test for conductivity

Cement Treated Pavements

Over the years pavements with cement treated layers have exhibited different performances depending on three factors, namely structural composition, load amplitude and environment. Durability (chemical or physical decomposition depending on climate)

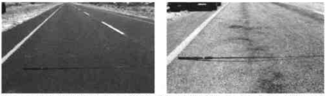
It is not always possible to find materials complying with the required specifications. Fortunately there are ways to improve unsuitable materials (within limits). Technique used will depend on:

- Technical requirements
- Materials available
- Economics

The choice needs to be made with these in mind. In this regard it is important to appreciate that compaction is by far the simplest and cheapest method of improving a range of materials. However, it should be understood that it does not change material properties except for affecting moisture movement!!

Deep compaction is particularly beneficial in reducing surface rutting that develops as a result of deep-seated consolidation under traffic. By doing this, the processed performance of the material is improved by decreasing voids and increasing particle interlock. [see Figures 24 (a) (b) and (c), Figure 25 (a) and (b)].

Figures 24 (a), (b) and (c) Typical compactors in SA



Figures 25 (a)(b) Typical effect of truck traffic on sections with and without deep compaction

The aim is to improve materials by decreasing voids and increasing particle interlock

This results in higher shear strength, lower permeability and less potential for permanent deformation. Change in material properties can be brought about by considering grading and plasticity of the material and ultimate strength requirement.

The question is then how this is done? Clearly it can be done by blending one or more materials and this is

Figures 26 (a), (b) and (c) Typical distress of sections with CSCR

frequently successfully applied. The alternative is to consider bound materials using cement, lime or other pozzolans such as slagment. Bitumen emulsion and foam asphalt can also be used. Factors that need to be borne in mind are:

- Maximum aggregate size
- Atterberg limits

- Rule: PI<10 cement, PI>14 lime, in between use either

- Design strength (UCS or ITS or semi-circular bending tensile strength)
- Durability

Two processes can be considered each requiring due regard for factors that impact on performance:

- Modification - where the influence of the clay is reduced. Materials with Plasticity Index > 12 are treated with hydrated lime. Slight increase in bearing capacity.
- Cementation - sandy materials, PI < 12, are treated with cement to increase strength and bearing capacity. Invariably this leads to cracking at intervals of between two and four meters

Durability of bound materials requires attention to the following:

- Gravel initial consumption of lime (ICL)
- Unconfined compressive strength test on carbonated or cycled specimen
- Wet/dry brushing test / erosion resistance

This phenomenon affects primarily marginal quality materials. Pozzolanic reaction products and free lime react with carbon dioxide in the air and soil air. This reduces the pH and the cementitious products become unstable and breakdown.

All strength can eventually be lost. Clear evidence of this is frequently found. The cause lies in the fact that clay absorbs stabilizer. If insufficient stabilizer content is provided there is no stabilizer available for long-term benefit.

Tests for this phenomenon can be best be done by performing the ICL test developed by Eades and Grimm thus ensuring that the saturated solution of soil and lime has a pH >12.4. Other requirements are as follows:

- ITS strength:
- C3 250 kPa @ 95-97% Mod AASHTO
- C4 200 kPa @ 95-97% Mod AASHTO

  *(alternatively consider the semi-circular bending tensile strength)

- Max wet/dry Brushing loss:
- C2 5%
- C3 20%
- C4 30%
- Min stabilizer content should be set equal to the ICL plus 1% to resist carbonation. In order to cater for losses on site it may be prudent to add half percent of 0.5%.

There are a number of means of improving poor materials. Need to be assessed on appropriateness and cost. South Africa is making more use of recycling. This will involve reusing old roads and waste materials and their improvement. It will be important to evaluate pavement performance prudently before embarking too enthusiastically on this route.

MECHANISMS OF DISTRESS

Typical forms of primary distress are rutting, cracking, debonding and disintegration of the asphalt surfacing resulting in potholes. These phenomena occur as a result of the action of the different mechanisms of distress listed in Table 6, individually or collectively. In the Synthesis 325 (Hugo and Epps Martin, 2004) a wide range of distress mechanisms were identified as being operational in pavement systems or impacting on pavements. Many of these are also present in South Africa. These have been demarcated in Table 6. As could be expected, the structural composition and the pavement materials are the major driving factors. It is imperative that these mechanisms are well understood and catered for in order to prolong pavement performance life or provide guidance to newcomers to pavement engineering.

From the information gathered for the Synthesis 325 (Hugo and Epps Martin, 2004) study it was apparent that the primary form of distress of LCP layers was initially related to the action of water, subsequently leading to fatigue of the material. This appears to be similar to the experience of China.

Table 6 Selected Mechanisms of Distress (after Hugo, 2004)

DISTRESS FACTOR	
6.1 MOISTURE DAMAGE	
6.1.1 Stripping/ surface fatigue	X
6.1.2 Strength loss of pavement layers due to fatigue and or chemical distress: -Base and sub-base; -Subgrade Ingress of water, pumping and erosion follows	
6.1.3 Freeze-thaw (interaction between temp/water)	X
6.1.4 Chemical Distress e.g. carbonation	
6.2 LOAD DAMAGE (Wheel loading)	
6.2.1 Temperature High (rutting)	X
6.2.2 Temperature Low (fatigue)	X
6.2.3 Temperature Below freeze point (freeze - thaw)	
6.2.4 Load Intensity	X
6.2.5 Suspension type	X
6.2.6 Tire pressure/type ; configuration; contact stress	X
6.2.7 Axle configuration	X
6.2.8 Trafficking Direction in APT (unidirectional versus bi-directional)	X X
6.2.9 Lateral Wander	X
6.2.10 Speed/Frequency	X
6.2.11 Braking/Incline trafficking	X
6.3 STRUCTURAL FLAWS / DISCONTINUETIES	
6.3.1 Micro-fracturing and volume change due to ASR	X
6.3.2 Debonding	X
6.3.3 Disintegration of material, pumping and erosion leading to voids. Stress conditions are no longer determined by continuity of structure.	X

DIAGNOSTIC STUDIES

In cases of poor performance, diagnostic studies are often done. These enable the damage to be analyzed and surveyed so that a review of the impact can be considered. Those that occur in South Africa have been demarcated in the table. A tool that has been used very successful is the model mobile load simulator (MMLS3). A case study of such an application has been reported (Hugo et al 2004). With this device it is possible to simulate some of the distress mechanisms during diagnostic studies, and that enables the user(s) to select appropriate maintenance or rehab.

REHABILITATION OPTIONS

Different methods of rehabilitation are being, or have been used in South Africa depending on the nature and extent of the distress. Some excellent case studies have been published (Steyn et al, (1997) ;Servas et al, (1997) and Strauss et al,(1985). Many of these, if not all, have some connection to APT (Hugo, 2004). The following is a list of some of the options:

- Double seal (S2) or thin asphalt (50mm);
- Rip and reconstruct aggregate base (G1 or G2) with seal coat or asphalt surfacing (note emulsion treatment often used for the base);
- Crack and seat CTCR and overlay with G1 granular base and surfacing;
- Use of recycled asphalt pavements (RAP) using up to 70 percent;
- Bitumen-rubber overlays with extender oil added;
- Deep in situ recycling using emulsion- or foam-treated bases with or without blends of cement or other pozzolanic material such as slagment;
- Rubber stress-relieving interlayer, woven and non-woven geofabric interlayer (SAMI);
- Continuously reinforced concrete (CRCP) overlays;
- Effective use of pothole fillers.

Final selection can generally be made after considering the results of the diagnostic studies. The procedure has been described in TRH 12 (SANRAL, 1998). Sometimes further investigation may be needed involving APT (full-scale and/or third -scale) (Strauss et al, 1985; and Hugo et al, 2004) to establish feasibility of proposed options and the expected performance. In other cases, rehab may be postponed in favour of maintenance if the distress does not warrant rehab. Determination of causal mechanism (s) and constructability are both considered as inherent parts of the rehabilitation process.
The following three case studies utilized APT to evaluate the rehab options.

Case study #1: Route N2 ASR rehab, South Africa
This case was extensively discussed in the Synthesis 235 (Hugo and Epps Martin, 2004).
- 35 mm bitumen-rubber overlay with stress absorbing membrane on 200 mm jointed concrete slab, 100 mm cement stabilized base, 75 mm gravel subbase on sand subgrade
- Ingress of water and air, prevented by rehab. With drainage installed on outer edge. Hence no pumping and disintegration. Only minor reflection cracks thus far after application of 6 million E80s.

Conclusion: Expected performance life 20 years or > 9 million - E80s. This is considerably more than anticipated after excessively wet HVS trafficking

Case Study #2: Rehabilitated HVS test pavements - Gauteng, South Africa
The SA-HVS examined performance of three rehabilitation options for lightly cemented pavements (LCP) (Steyn et al. 1997).
- bleeding of the double seal and surface deformation on low volume pavement LC pavement < 3xE6-E80s
- pumping of fines in the wet condition found with trafficking of cracked and seated LCP with 35-50 mm HMA. Similar performance with G1 base and double seal surfacing

Conclusion: Solutions cost-effective for traffic volumes between 3 and 30 million E80s

Case Study #3: Highway B1, south of Windhoek - Namibia
In Namibia an overlay of a highway was tested during construction to evaluate effect of field density and addition of lime additive to counteract stripping (Hugo et al, 2004)
- 35 mm dense graded asphalt overlay on gravel base with surface seal evaluated with MMLS3 under heated wet and dry trafficking (50C) to evaluate performance. Aggregate known to be susceptible to stripping.
- Rutting found acceptable and retained semi-circular tensile bending strength found >80 percent, which is acceptable.

Conclusion: Performance life expected to reach design requirement of 5.6 million E80s

NEW DEVELOPMENTS

A study is being planned in Mozambique to investigate the cost effective application of LCP's using full-scale (MLS10) and one third scale (MMLS3) APT devices. For the benefit of delegates the protocols thus far developed for the MMLS3 are briefly set out below (Hugo et al 2004).

Interim protocols for evaluating MMLS3 rutting and moisture damage (Hugo et al., 2004).

There are currently ten MMLS3 users worldwide. With the expansion of the users group conducting APT with the MMLS3 it has become feasible to compile a draft protocol for the application of the device for evaluating rutting and moisture sub damage.

The comparative results from MMLS3 and full-scale trafficking at the test track of the National Center for Asphalt Technology (NCAT) (Smit et al 2003, Smit et al 2004) and WesTrack (Epps et al 2003) were used as benchmarks for establishing criteria for acceptable rutting performance. The results of tests in Texas (Walubita et al 2002) were used as guidelines for establishing criteria for moisture damage. The interim protocols are set out below:

□ When considering the rutting performance fundamentally, vertical stress profiles under the respective wheels are used for purpose of comparison. The limiting rut depth has to be determined in terms of expected traffic, lateral wander, climatic conditions during life cycle, tyre pressure and layer thickness

□ General rutting performance guidelines at critical temperature* (normally 50C or more) and 7200 load applications per hour are:

o < 3mm after 100k MMLS3 load applications on roads and highways

o <1,8 mm after 100k MMLS3 load applications on airports

*Critical temperature conditions are determined from the hottest seven (7) period in a selected number of years according to SHRP Manual 648A (SHRP 1994)

□ For determining moisture susceptibility of HMA surfacings using wet trafficking after 100k applications at 50C heated wet MMLS3 axles:

o SCB residual strength of HMA 80%

o SASW residual stiffness 80% and

o SCB fatigue ratio 50% for hot mix asphalt

□ Composite pavements require special consideration to evaluate entrapment of water. Values should be adapted to suit less critical trafficking conditions

□ Construction and quality control must ensure that the design assumptions are satisfied.

CLOSURE

The presentation was aimed at transferring some South African experience to China. I trust that I have achieved this and that I have awakened the interest of delegates. The important thing to remember is that pavements are very complex needing an open mind and innovative approach. Last but not least, the thing to remember is that, water leaks through all theory! If pavements are dry they can carry exceptional loads. This has been proven conclusively with APT. However, wet trafficking by a light truck could be potentially as damaging to the road surface as a much heavier vehicle. On the surface on the road it is contact stress that is important!

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REFERENCES

- De Beer, M., 1997 Determination of Pneumatic Tire/ Pavement Interface Contact Stresses Under Moving Loads and Some Effects on Pavements with Thin Asphalt Surfacing Layers, Proceedings of the 8th International Conference on Asphalt Pavements, Seattle, Wash., Aug. 10- 14.
- Freeme, C.R., Pavement Behaviour and Rehabilitation, 1984, Annual Transportation Convention, Symposium on Recent Findings of Heavy Vehicle Simulator Testing, Presented by the National Institute for Transport and Road Research, Pretoria, South Africa, Aug., Chap. 1, p. 22; Chap. 3, p. 36.
- Hugo F and Martin Epps, AL, 2004 , NCHRP Synthesis of Highway Practice 325 Significant Findings from Full-scale Accelerated Pavement Testing, Transportation Research

Board, National Research Council, Washington, D.C., 2004, 201 pp

• Hugo, F., De Witt, R., Helmich, A., 2004, Application of the MMLS3 as APT tool for evaluating asphalt performance in Namibia, Paper accepted for publication and for presentation at 8th Conference on Asphalt Pavements for Southern Africa

• National Institute for Transport and Road Research (NITRR), 1978, Technical Recommendations for Highways: Structural Design of Road Pavements, Draft TRH4, Pretoria, February.

• National Institute for Transport and Road Research (NITRR), 1985, Technical Recommendations for Highways: Structural Design of Interurban and Rural Road Pavements, Draft TRH4, Pretoria.

• Nordengen, P.A., 2002, Strategic Development - overload control, South African Advanced Road and Transport Technology Forum, Chengdu, China, 20 - 22 November.

• Otte, E, 1977, Structural Design Procedures for Cement-treated Layers in Pavements, 1977, PhD thesis, University of Pretoria, South Africa.

• Rust, F.C., S.V. Kekwick, E.G. Kleyn, and E.S. Sadzick, 1997 The Impact of the Heavy Vehicle Simulator (HVS) Test Programme on Road Pavement Technology and Management, Proceedings of the 8th International Conference on Asphalt Pavements, Seattle, Wash., Aug. 10-1.

• Servas, V.P., M.A. Ferreira, and P.C. Curtayne, 1987, Fundamental Properties of Recycled Asphalt Mixes, Proceedings of the 6th International Conference on Asphalt Pavements, Ann Arbor, Mich., Vol. 1, pp. 455-465.

• Smit, Andr"l. de Fortier., Hugo, Fred. Rand, Dale Powell, Buzz, 2003, Model Mobile Load Simulator Testing at National Centre for Asphalt Technology Test Track, Transportation Research Record 1832, Journal of the Transportation Research Board, Washington, D. C. USA, October.

• South African National Roads Agency Ltd (SANRAL), 1987, Technical Recommendations for Highways: Guideline for Road Building Materials, Draft TR14, Pretoria

• South African National Roads Agency Ltd (SANRAL), 1994, Technical Recommendations for Highways: Pavement Management Systems, Draft TR22, Pretoria

• South African National Roads Agency Ltd (SANRAL), 1996, Technical Recommendations for Highways: Surfacing Seals for Rural and Urban Roads, Draft TRH3, Pretoria

• South African National Roads Agency Ltd (SANRAL), 1996, Technical Recommendations for Highways: Structural Design of Flexible Pavement for Interurban and Rural Roads, Draft TRH4, Pretoria

• South African National Roads Agency Ltd (SANRAL), 1998, Technical Recommendations for Highways: Flexible Pavement Rehabilitation Design, Draft TRH12, Pretoria

• Steyn, W.J. vdM., M. De Beer, and A.T. Visser, 1997, Thin Asphalt and Double Seal Rehabilitated Lightly Cemented Pavements: Evaluation of Structural Behavior and Life Cycle Costs," Proceedings of the 8th International Conference on Asphalt Pavements, Seattle, Wash., Aug. 10-14.

• Steyn, W.J. vdM., M. De Beer, and A.T. Visser, 1997Thin Asphalt and Double Seal Rehabilitated Lightly Cemented Pavements: Evaluation of Structural Behavior and Life Cycle Costs, Proceedings of the 8th International Conference on Asphalt Pavements, Seattle, Wash., Aug. 10-14.

• Strauss, P.J., J. Du Plessis, V. Francis, and A.W. Viljoen, 1985, The Application and Validation of an Analytical Method in the Structural Rehabilitation of a Cracked Rigid Pavement, Proceedings of the 3rd International Conference on Design and Construction of Concrete Roads, Purdue, April.

• Theyse, H.L., M. De Beer, and F.C. Rust, 1996, Overview of South African Mechanistic Pavement Design Method, Transportation Research Record 1539, Transportation Research Board, National Research Council, Washington, D.C., , pp. 6-17.

• Walker, R.N., 1985 The South African Heavy Vehicle Simulator, Accelerated Testing of Pavements Session, Proceedings of the Annual Transportation Convention, Pretoria, South Africa, July 29-Aug. 2.

• Walker, R.N., Paterson, W.D.O., Freeme, C.R., and Marais, C.P., 1977, The South African Mechanistic Design Procedure. Proceedings Fourth International Conf. on the Structural Design of Asphalt Pavements, Ann Arbor, Michigan, August.,

• Walubita, L.F.; Hugo, F.; Epps Martin, A.L., 2002. Indirect tensile fatigue performance of asphalt after MMLS trafficking under different environmental conditions, Journal of the SA Institution of Civil Engineering, Vol. 44-3, pp. 2-11, Johannesburg, South Africa.■