CHAPTER 1 INTRODUCTION AND OBJECTIVES

1.1 HISTORICAL BACKGROUND

1.1.1 Roads

Transportation has been an important aspect of human life since the beginning of mankind. Roads linked ancient cities for purposes of trade. When empires arose, trade routes became a primary concern of kings for the stability of their governments. In ancient times roads served the needs of commerce, the military and the pilgrim.

The Encyclopaedia Britannica (1973) makes reference to Persian, Mesopotamian, Chinese and Indian roads during the pre-Roman time. These roads consisted mainly of clearing and levelling, with cuts and fills restricted to a minimum. Traffic was mainly restricted to pedestrians, horsemen, chariots and caravans.

The first scientific road builders were the Romans between 350BC and 200AD. They constructed roads of high standard for their time, with relatively straight horizontal and vertical alignments, various foundation layers and proper drainage. The pavement layers consisted of gravels with aggregates varying from 600 mm in size to as fine as sand. Stabilisation of layers consisting of sand or finer gravel with lime was not uncommon.

With the decline of the Roman, Chinese and Mayan empires, the road system fell into centuries of disrepair. In the last half of the 18th century the fathers of modern road building, Pierre-Marie-Jérôme Trésaguet (1716-1796), John Metcalf, Thomas Telford (1757-1834) and John Loudon MacAdam (1756-1836), applied their trade in France and England.

With the introduction of the motorcar, capable of high speeds, the alignment and road surfaces suitable only for horses and pedestrians were completely inadequate. This brought the importance of roads to the foreground that stimulated the need for research in pavement materials and pavement design. Research into these fields commenced well into the twentieth century and led to major improvements to the concepts developed by the early pioneers.

Most developments in modern pavement design took place in the United States and Europe. The AASHO road test, conducted between 1958 and 1961, provided valuable information on the empirical design of pavement structures, while the work of Westergaard (1926), Burmister (1943) and Ahlvin and Ulery (1962), allowed for the calculation of stresses and strains in elastic layered systems for a more analytical approach. The calculation of stresses and strains in pavement structures, caused by a wheel load, was therefore made possible.

1.1.2 The use of bituminous products in road building

The first recorded use of native bitumen in road construction, appears to be about 700 BC, when Naboloplasser, King of the Babylonians, had a road built of burnt bricks jointed with bitumen (Road Emulsion Association, 1958). After this period the use of bitumen in road-making appears to have been forgotten until the 19th century, except in the work of the Incas of Peru during the 14th and 15th centuries. They constructed the most remarkable system of roads, some of which are said to have been paved using asphalt; unfortunately no details of the work seem to have been recorded.

Bitumen was not used by the early pioneers in road building. Although the Val de Travers deposits of asphalt were discovered as early as 1712, they were not actively exploited until 90 years later. Residues from the distillation of crude oil were being used in surface treatments of roads in the early years of the 20th century in the US. Later on, it was discovered that the addition of suitable volatile solvents to the very viscous residues permitted their cold application. Until the introduction of emulsions in the early 1900's, it was in general necessary for all bitumens and their compounds to be heated prior application, to render them sufficient liquid.

1.2 THE USE OF BITUMEN EMULSION IN BASE LAYERS.

Bitumen emulsions were first manufactured in South Africa in 1927 (Marais and Tait: 1989) and initially used in surface treatments and slurry seals. Over the past 30 years, great success has been achieved by South African road engineers with the technique of adding small quantities of bitumen emulsion to gravels of fair to good quality. Between 1982 and 1992, the South African Bitumen Association (SABITA) sponsored a research programme to develop acceptable mixing, testing and evaluation methodologies for Granular Emulsion Mixes (GEMS). The emphasis of that project was on the upgrading of substandard materials to base layer standards by adding relatively high percentages of emulsion (in excess of 2% net bitumen). In October 1993, SABITA launched a design manual (SABITA: 1993) for GEMS with recommended design procedures for both stabilised GEMS (high emulsion contents) and modified GEMS (low emulsion contents). While ETB (Emulsion Treated Bases) includes the use of bitumen emulsion for upgrading substandard materials, the term GEMS also covers the addition of emulsion to other types of granular material such as:

- Substandard materials
- Granular materials of better quality
- Recycled granular, cement- and lime treated bases or a combination thereof.

A number of shortcomings in the above-mentioned manual resulted in the project launched by SABITA in 1996 to broaden the range of application of Emulsion Treated Bases (ETB's) as a competitive base course material. This was done by extending the design scope of the current technology and entrenching it in practice. This project provided economic guidelines as well as material design and construction guidelines (SABITA, 1999). Although this project provided guidelines on the structural design of ETB's, it was mostly based on the experience of road engineers.

The advantages of emulsion treated layers are well known and documented (Horak et al: 1992, Lewis et al1999 and SABITA 1999), but little scientific knowledge on the performance and failure mechanism of emulsion treated layers are available.

1.3 THE SOUTH AFRICAN MECHANISTIC PAVEMENT DESIGN PROCEDURE

The first simplified mechanistic design procedure in South Africa was developed by Van Vuuren, Otte and Paterson in the early 1970's (Van Vuuren et al: 1974). At the International Conference on the Structural Design of Asphalt Pavements in 1977 in Michigan, Walker et al. (1977) published the first comprehensive statement on the state of the art of mechanistic pavement design in South Africa. The procedure was refined and improved since then, and in 1995 it was updated by Theyse (1995) and Theyse et al (1995) for the purpose of revising the TRH4:1985 (CSRA: 1985).

The procedure provides values for the characterisation of pavement materials and includes the following features (Maree and Freeme: 1981 and Theyse: 1996):

- Transfer functions for thin asphalt surfacing (continuously and gap graded) layers as a function of the maximum horizontal tensile strain at the bottom of the layer,
- Transfer functions for thick asphalt base layers as a function of the maximum horizontal tensile strain at the bottom of the layer for a range of stiffness values from 1 000 to 8 000 MPa,
- Fatigue transfer functions for crack initiation of cemented material as a function of the maximum tensile strain at the bottom of the layer,
- Transfer functions for crushing failure of cemented material as a function of the vertical compressive stress at the top of the cemented base.
- Transfer functions for granular materials (crushed stones and natural gravels) as a function of the safety factor against shear failure.
- Transfer functions for in situ subgrades as a function of the maximum vertical compressive strain at the top of the subgrade.

The existing South African Mechanistic Pavement Design Procedure is being used extensively in new pavement design and rehabilitation in South Africa and was used to develop the

TRH4:1996 (CSRA: 1996). It does not however include any transfer functions or failure criteria for layers treated with small quantities of bitumen emulsion.

1.4 THE NEED FOR A FORMAL DESIGN PROCEDURE FOR PAVEMENTS WITH EMULSION TREATED LAYERS.

Previous research (Kari: 1969, Marais and Tait: 1989, SABITA: 1993, SABITA: 1999 and Santucci: 1977) provides valuable knowledge on the material design, construction techniques and quality control of GEMS and ETB's.

The structural design methods available for emulsion treated layers are mostly based on experience by road engineers. Although some indication exists that the behaviour of an emulsion treated layer should be similar to that of a cement treated layer, no performance prediction model exists for emulsion treated material (Theyse: 1997). Due to the fact that emulsion treated layers are being used more frequently, the need for a rational structural design method based on the principles of the South African Mechanistic Pavement Design Method, arise and need to be developed.

1.5 OBJECTIVES OF THE STUDY

The main objectives of this study are to define the life cycle behaviour and failure criteria of pavement layers treated with bitumen emulsion and to develop transfer functions for the relative mode of failure to load repetitions for emulsion treated layers.

A secondary aim of the study would be to provide input into the development of a structural design manual for emulsion treated layers based on the principles of the South African Mechanistic Pavement Design Procedure.

1.6 SCOPE AND EXTENT OF THE STUDY

The scope and extent of the study includes a detailed literature review, detailed laboratory testing on emulsion treated materials as well as additional tests with the Heavy Vehicle Simulator (HVS).

The literature study will review historical data from previous HVS- and laboratory tests on emulsion treated materials where possible.

The laboratory tests in this study were performed on a ferricrete with various cement and net bitumen content. The cement was below 2 % while the net bitumen content never exceeded 3 %. The HVS tests in this study were conducted on ferricrete stabilised with 3 % bitumen emulsion (1.8% net bitumen) and 2 % cement.

Results from the literature review, laboratory- and field tests will be utilised to define the life cycle behaviour and failure mechanism of pavement layers treated with bitumen emulsion.

Transfer functions will be developed to serve as an input into a structural design manual and the South African Mechanistic Pavement Design Method. A design catalogue will be proposed for the use as a design aid according to the principles of the TRH4 structural design guide.

1.7 STRUCTURE OF THE DISSERTATION.

In Chapter 2 a literature review on the mix design and engineering properties of emulsion treated layers are given. Information obtained from this literature review is used to define aspects relevant to the structural design process.

Chapter 3 is a literature review to determine the state of knowledge on the structural properties and existing structural design procedures for pavements containing emulsion treated layers. Historical data from previous laboratory and HVS tests are evaluated.

Chapter 4 discusses developments towards mechanistic-empirical design models.

Chapter 5 comprises an experimental program that includes laboratory and field tests. Laboratory tests include static and dynamic triaxial tests while the field tests include tests with the HVS under various wheel loads. The results from these tests and the performance of the emulsion treated material under laboratory and Heavy Vehicle Simulator testing are presented and discussed.

Chapter 6 discusses the fatigue life properties of the emulsion treated materials from the data obtained from the laboratory and field tests. A failure criteria are developed for fatigue life and design curves for the fatigue life of emulsion treated materials are proposed.

Chapter 7 discusses the permanent deformation properties of and emulsion treated material and the data from chapter 5 are used to develop transfer functions and design curves for permanent deformation.

Chapter 8 discusses the structural design of pavements with emulsion treated layers. A design method based on the South African Mechanistic Pavement Design Method is proposed as well as a design catalogue according to the principles of the TRH4.

Chapter 9 contains the conclusions of the main findings of the study and demonstrate that the study objectives were fulfilled. Recommendations for further research are also made.

1.8 REFERENCES

Ahlvin RG and Ulery HH, 1962, *Tabulated values for the determining the complete pattern of stresses, strains and deflections beneath a uniform circular loading on a homogeneous half space*, Highway Research Board Bulletin no 342, Transportation Research Board, Washington DC, Unites States.

Burmister DM, 1945, *The general theory of stresses and displacements in layered systems I, II and III*, Journal of Applied Physics, Vol. 16, no. 2.

Committee of Land Transportation Officials (COLTO), 1996, TRH4: *Structural design of interurban and rural road pavements*, TRH4, Department of Transport, Pretoria, South Africa.

Committee of State Road Authorities (CSRA), 1985, TRH4: *Structural design of interurban and rural road pavements*, TRH4, Department of Transport, Pretoria, South Africa.

Horak E and Rust FC, 1992, *The performance and behaviour of bitumen emulsion treated road bases in South Africa*, Proceedings of the 7th International Conference on Asphalt Pavements, Nottingham, United Kingdom.

Lewis AJN and Collings DC, 1999, *Cold in-place recycling: a relevant process for road rehabilitation and upgrading*, Proceedings of the 7th Conference on Asphalt Pavements in Southern Africa, Victoria Falls, Zimbabwe.

Marais CP and Tait MI, 1989, *Pavements with bitumen emulsion treated bases: Proposed material specification, mix design criteria and structural design procedures for South African conditions*, Proceedings of the 5th Conference on Asphalt Pavements in Southern Africa, Swaziland.

Road Emulsion Association, 1958, *Modern road emulsions*, 3rd ed., Road Emulsion Association Ltd., London.

SABITA, 1993, *GEMS: The design and use of granular emulsion mixes*, Manual 14, SABITA, Cape Town, South Africa.

SABITA, 1999, *ETB: The design and use of emulsion treated bases*, Manual 21, SABITA, Cape Town, South Africa.

Santucci LE, 1977, *Thickness design procedure for asphalt and emulsified asphalt mixes*, Proceedings of the 4th International Conference on the Structural Design of Asphalt Pavements, An Arbor, United States, pp 424 – 456.

Theyse HL, 1995, *TRH4 Revision 1995, Phase II: Mechanistic Design of the Pavement Structures in the TRH4 Pavement Design Catalogue*, National Service Contract NSC24/2, Transportek, CSIR, Pretoria, South Africa.

Theyse HL, de Beer M, Prozzi J and Semmelink CJ, 1995, *TRH4 Revision 1995, Phase I: Updating the Transfer functions for the South African Mechanistic Design Method, National Service Contract NSC24/1*, Transportek, CSIR, Pretoria, South Africa.

Theyse HL, de Beer M and Rust FC, 1996, *Overview of the South African Mechanistic Pavement Design Analysis Method*, Divisional Publication DP-96/005, Transportek, CSIR, Pretoria, South Africa.

Van Vuuren DJ, Otte E and Paterson WDO, 1974, *The Structural Design of Flexible Pavements in South Africa*, Proceedings of the 2nd Conference on Asphalt Pavements in South Africa, Durban, South Africa.

Walker RN, Paterson WDO, Freeme CR and Marais CP, 1977, *The South African Pavement Design Procedure*, Proceedings of the 4th International Conference on the Structural Design of Asphalt Pavements, University of Michigan, Ann Arbor, Michigan, Unites States.

Westergaard HM, 1926, *Stresses in Concrete pavement computed by theoretical analysis*, Public Roads Vol. 7, no. 2, United States.