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# ROAD RECONSTRUCTION IN CAPE TOWN



HALF THESIS FOR THE MASTERS DEGREE IN CIVIL  
ENGINEERING  
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## Acknowledgements

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  - 2 The City of Cape Town who have funded this work.
  - 3 My wife, Debra, for her support.
  - 4 The front page photograph shows Plein Street in the 1880's and is reproduced from Fish Horns and Hansom Cabs by Eric Rosenthal, 1977.
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## Terms of Reference and Declaration

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### **Terms of Reference**

This thesis is submitted for the half thesis requirement towards the Masters Degree in Civil Engineering.

### **Declaration**

I, Mark Bondiotti, hereby declare that this thesis is my own work and it has not been submitted for a degree at any other university.

Mark Bondiotti  
March 2002

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### Synopsis

The objective of this thesis is to summarise a strategy that has been developed to solve the rehabilitation and reconstruction needs for the City of Cape Town. The thesis thereby provides a summary of the historical and geological context of road construction in Cape Town and provides guidelines and information that can be used by rehabilitation engineers working in the Western Cape. It also provides guidance for engineers working in other cities. The thesis is based on systems developed by the Author during his duties as Principal Materials Engineer for the City of Cape Town.

The thesis is divided into two sections. The first (chapters 2 & 3), considers data and information requirements wherein the historical and geological perspectives of road construction are presented.

Chapter 2 explores the history of road reconstruction. The evolution of pavement engineering is essential background information to engineers working in this field as it these pavements and materials that are encountered in today's projects. Pavement engineering has a long history stretching from the Ancient Egyptians to the designs of John Loudon Macadam and Thomas Telford who together formed the roots of modern pavement design. Many of the road foundations in Cape Town date back to the early 1900's when there was much experimentation with reconstruction techniques and the use of different materials. In the 1920's most of Cape Town's central streets were reconstructed and many of these pavements are still encountered today.

Chapter 3 summarises the geological perspective. Knowledge of the geology of the Western Cape is vital to all reconstruction projects as it determines the available materials and influences the structural behaviour of the road. The Table Mountain Group, the Cape Granite Suite and the Malmesbury Group form the major geological features under the Cape Town area and together with the pedogenic materials, they provide most of the available construction material.

In the second section of the thesis the system requirements are identified and addressed. The subsequent chapters explore pavement management systems, prioritisation models and specific case studies to demonstrate design and evaluation techniques.

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## Synopsis

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A Pavement Management System is used to monitor the road network and identify the roads that require reconstruction. The roads are then prioritised for reconstruction by rating them according to their condition, traffic class and serviceable life span. The roads ultimately selected are then subject to a rehabilitation investigation and detailed design, before construction is implemented.

In chapters five and six the attention shifts to project level systems. Case studies for specific design techniques and the evaluation of their effectiveness are presented.

The cold insitu recycling and concrete road rehabilitation techniques have been selected as case studies as there is presently a great demand for this type of reconstruction work in Cape Town. Four roads that were recycled between 1994 and 1997 have been evaluated using Dynamic Cone Penetration surveys and the South African Mechanistic Design Method. This has been done to demonstrate and develop design and evaluation tools and to determine the success of the process.

Several methods of concrete road rehabilitation have been used in Cape Town. The methods have been rated according to a visual and cost comparison. The saw cut method is favoured but further research needs to be done on the crack and seat method which shows much promise.

In conclusion, the reconstruction and rehabilitation needs in a city environment can be effectively managed by adopting a systematic approach based on the accumulation of data and information requirements and the development of design and evaluation systems.

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## Glossary

$\epsilon$	Strain
$\sigma$	Stress
BPN	Bitumen penetration
CBR	California Bearing Ratio
CIR	Cold insitu recycling
CGWC	Continuously graded asphalt wearing course
CTB	Cement treated base
CTSB	Cement treated subbase
DCP	Dynamic cone penetrometer
DN	Average penetration rate
DSN <sub>800</sub>	Number of blows to penetrate 800 mm into the pavement
E	Stiffness modulus
E80	Standard 80 kN axle load
ETB	Emulsion treated base
FCI	Functional condition index
GCI	General condition index
ITS	Indirect tensile strength
LCI	Structural condition index
LL	Liquid limit
MCI	Maintenance condition index
PADS	Mechanistic-empirical Pavement Analysis and Design Software
PI	Priority index
PI	Plasticity index
SAMDM	South African Mechanistic Design Method
SCI	Surface condition index
UCS	Unconfined compressive strength
VCI	Visual condition index

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## **Chapter 1: Introduction**

### **1.1 Background**

The idea for this thesis originated in 1995 when the Author was asked to set up a Materials Division for the City of Cape Town's Roads and Stormwater Directorate. A top priority identified for this Division was to develop guidelines for the City's road reconstruction and rehabilitation responsibilities. It became apparent that very little local information was available and international and national guidelines were not readily applicable because of the unique character of the existing road structures, climate and geology.

### **1.2 Objectives**

The objective of this thesis is to summarise a strategy that has been developed to solve the rehabilitation and reconstruction needs for the City of Cape Town.

The document draws on definitive texts on the geological and historical development of roads in the Western Cape, as well as work done by the Author since 1995. This includes developing:

1. A data base of existing road structures.
2. Identification of the typical modes and types of road failures occurring in Cape Town.
3. A selection and prioritisation model.
4. Development of design methods and specialised rehabilitation techniques suited for Cape Town's requirements.

The purpose of this thesis is to provide:

- a summary of the historical and geological context of road construction in Cape Town,
- guidelines and information that can be used by rehabilitation engineers working in the Western Cape and
- guidance for rehabilitation engineers working in other cities.

### **1.3 Scope and limitations**

The thesis essentially consists of two sections. The first considers the data and information requirements in order to present the context of the problem. In this section, the first chapter presents the international and local development of pavement structures, as well as data on local pavement materials and types. This is followed by the geological context, where the local geology is described in order to identify the local pavement materials and their characteristics.

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In the second section the system requirements are identified and addressed. Chapter four focuses on network level systems where a pavement management system for prioritisation and rehabilitation is presented. In chapters five and six the attention shifts to project level systems. Case studies of specific design techniques and the evaluation of their effectiveness are presented. The thesis is concluded with a summary and recommendations in chapter seven.

Whilst the scope of the thesis is specifically limited to systems developed for Cape Town, the approach can be adapted for other cities. In addition, where relevant and available, national and international practice is cited.

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**SECTION 1**

**DATA AND INFORMATION  
REQUIREMENTS**

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## Chapter 2: Historical Perspective

This chapter examines the history of pavement materials and design. The first section looks at the broader world history of road building which gives a background to the different pavement types and their development. A detailed investigation into road building in the Western Cape follows. This information is essential to contemporary pavement engineers as it is these materials and pavement structures that are being rehabilitated today.

### 2.1 The world historical development

The Chinese were already building roads in 4000 BC. Some of the earliest formal roads were probably constructed by the Persian, Assyrian and Minoan civilisations using massive stone blocks placed directly on the subgrade. Remains of Minoan roads from about 3000 BC can still be seen today in the ruins of Knossos on the island of Crete. King Cheops of ancient Egypt had a stone-paved road, about one kilometre long, built in 3000 BC to carry limestone blocks for the Great Pyramid. In about 2600 BC, the Egyptians built a 10 kilometre, absolutely straight road, paved with sandstone and limestone for the purpose of carrying basalt to the Sakkara Necropolis to be used for statues and tomb floors.

The Romans developed a road system with a total length of about 30 000 kilometres. The roads were primarily constructed for military use. The Roman roads were constructed with a lower layer of flat stones, between 250 and 600 mm thick, followed by a 225 mm layer of smaller stone mixed with lime and topped with 300 mm of Roman concrete. This was topped with a 300 mm thick wearing course of flint-like lava stone which was packed tightly together like a modern block pavement. The total pavement structure was over a metre thick and well drained with a crown, hence the Roman roads were incredibly robust and some of them are still in use today.

After the fall of the Roman Empire there was no progress in road building until the 18<sup>th</sup> century when a French engineer, Pierre-Marie Jerome Tresaguet (1716-1796), designed roads based on the Roman method. His roads were constructed with a 250 mm thick layer of uniform stones laid edgewise on top of a prepared subgrade. A surfacing layer with a prominent cross fall was then added by covering the base with a layer of walnut-size broken stone.

The roots of modern pavement design came from John Loudon Macadam (1756-1836) and Thomas Telford (1757-1834) who were born in Scotland. Thomas Telford constructed a subbase out of large rocks of approximately 125 x 75mm and 325 mm thick, which were placed tightly against each other. Smaller rocks and chippings were then rammed into the openings from above and protruding points knocked off. This layer was then covered with a 100 mm base of smaller broken stone and gravel. A cambered wearing course of gravel or small stones was then added. Telford built more than a thousand kilometres of these roads. The original macadam road consisted of a base of single sized stone, of about 25 mm by 50 mm, laid in layers of 75 mm thickness. The stones were closely packed and the voids then filled with a finer material. Later improvements involved slushing in the finer material with water. This led to the development of waterbound macadam.

Eli Whitney Blake developed the first crushed stone in 1858 and with the use of steamrollers for compaction, the 1860's allowed for the construction of thicker base layers. After the invention of the motor vehicle in the latter part of the 19<sup>th</sup> century it became necessary to bind the road surface to prevent fines being dislodged and causing ravelling and potholing. Bitumen and tar were sprayed or poured hot onto the coarse aggregate macadam base to fill the voids and seal the pavement. This technique was called bitumen penetration macadam.

Mechanisation in the 20<sup>th</sup> century lead to the development of smaller, well graded crushed stones which gradually replaced the labour intensive methods of Telford and Macadam. In developing countries there has lately been a resurgence in the use of labour intensive construction and waterbound macadam and block pavements are once again gaining in popularity. Figure 2.1 summarises the different techniques and shows how they have evolved.

[Acknowledgement is given to references 5, 8 & 12 which comprehensively cover this subject.]

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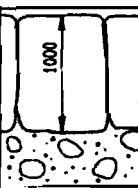

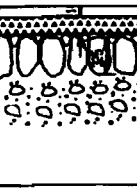
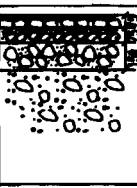
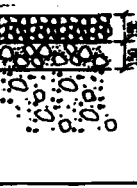
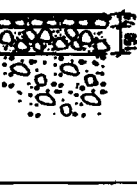
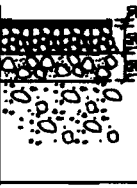
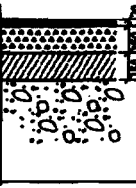
Period & era	Persian Mesopotamian Assirian ±2000 to ±500BC	Roman road building ±450BC to ±500AD	Traesguet ±1700 telford ±1810	Waterbound macadam ±1820 to ±1860	Macadam early mechanised ±1860 to ±1890	Bitumen macadam early mechanised ±1890 to ±1930	Surfaced macadam mechanised ±1930 to ±1960	High quality crushed stone base ±1950 to present
Equipment and technology breakthroughs	Wood, bronze and later iron tools. The discovery of the wheel.	Roman cement, iron and bronze digging and shaping tools. Horse-drawn carts and rollers.	Mauls, hammers, spades, horse-drawn carts	Forks, rakes, spades, hammers, horse-drawn carts/wagons and rollers.	Stone crusher 1856 (Blake). Heavy steam roller, 1860 (Avelling & Porter). Dynamite 1867 (Nobel).	Internal combustion engine 1861 (Lenoir) 1885 (Daimler).	Motorised graders, pavers and heavy rollers	Pneumatic and vibratory rollers
Traffic	Pedestrians, horse-drawn chariots, sledges, light wagons	Pedestrians, horse / ox-drawn carts, wagons and heavy war machinery.	Pedestrians, animal-drawn wagons, carts etc.	Pedestrians, animal-drawn wagons, carts etc.	Pedestrians, animal-drawn wagons, carts etc. Eight of vehicles increased.	Motorised vehicles with increased speed, weight and contact pressure.	Larger volumes of motorised vehicles with increasing weight, speed and contact pressure.	Larger volumes of motorised vehicles with increasing weight, speed and contact pressure.
Construction	Large rock blocks (500mm to 1000mm dimensions) placed by slave labour and animal power	Large stones (250 to 600) forming a roadbed covered with gravel and lime, a base of Roman concrete and a wearing course of dressed and shaped stone (300mm thick).	Broken stone (100mm) placed on foundation layer of rock (75x125x325mm) smaller stone driven into voids and protruding points broken off.	Patented design. Omission of Telford layer. Broken stone 50-75mm placed by hand with forks, rakes & spades in 75mm layers with stone on stone interlock. Voids filled with filler material and bound with water and horse-drawn roller.	Crusher facilitated single sized stone production and bigger layer lifts (150mm to 200mm) made possible by steam roller.	Waterproofing with bitumen and tar poured and sprayed on single stone layers keyed-in with smaller stones (37mm to 26mm). Layer thickness 75mm to 100mm.	Premix hot asphalt surfacing placed (20mm to 50mm) on top of 150mm to 250mm water-bound macadam base. Rollers, pavers, graders provided mechanisation.	Premix hot asphalt surfacing placed (20 to 50mm) on top of crushed stone base with continuous grading (max. 37mm) placed by grader or paver. Vibratory rollers enhanced compaction. Cemented subbases construction enhanced structural capacity.
Structure								

Figure 2.1: Pavement evolution [5]

## **2.2 The early history of the Cape's roads (1653 to 1899)**

In 1653 Jan Van Riebeeck had a road built for wagons which consisted merely of a levelled pathway. One of these first roads was the wagon road between Table Bay and the forest above Kirstenbosch. It was a rough track that was kept level by men with picks and shovels. By 1666 the road to Kirstenbosch had been extended over Constantia Nek. It wasn't however, until the 19<sup>th</sup> century that proper road pavements were constructed.

In the 1820's the deplorable condition of Cape Town's roads was described in a report by Major W. E. C. Holloway [9]. He described that the 8.8 kilometres of road had deep holes and ruts and proposed urgent reconstruction. The roads were reconstructed by breaking up the existing material to a depth of 22.9 cm (9 inches) and covering this with a 20.3 cm (8 inches) layer of ironstone. Experiments with Macadam's methods were apparently not very successful. The filler material was described as disintegrating in the heat and then blowing away in the South Easter. The stones would then break loose and cause damage to the hooves of oxen. The gravel filler was probably not crushed fine enough to adequately bind the base.

By 1845 the first hard road was constructed across the Cape Flats and it was reported that the shifting sands often covered this road causing serious disruptions. The road was built on a raised causeway which was 4.9 metres (16 feet) high in places.

In 1854 and 1855 wooden paving blocks were applied to Adderley Street, Darling Street and Sir Lowry Road. This method was a failure and by 1858 the roads were so muddy that people would sink up to their calves in the mud. Sir Lowry Road was so badly potholed that omnibus passengers were warned that travel was unsafe.

In 1897 the first cars were introduced to Cape Town.

[Acknowledgement is given to references 1, 9 & 14 which comprehensively cover this subject.]

## **2.3 Road pavements in Cape Town (1900 to present)**

It was really only at the beginning of the 20<sup>th</sup> century that pavement engineering was applied in Cape Town. The following two sections trace the history of pavement design from the 1900's to the present.

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### 2.3.1 Early Developments (1900 - 1920)

In the early 1900's the City of Cape Town was experimenting with various different pavement types. In 1905 a tender was advertised by the City of Cape Town for the paving of the principal streets. Thirty-eight tenders were received for the paving of Adderley, St Georges, Darling, Parliament, Plein and Long Streets with various different materials including asphalt, granite, hardwood and creosoted red deal (see Appendix 1 which gives the full list of tenders; this is of interest as it shows the full range of materials that were available at the time). However the tender was not awarded and the Department of Public Works was asked to write a report on the different available paving options [11]. This shows that there was much debate at the time regarding what surfacings to use. A motion was later introduced suggesting that tenderers be invited to lay trial pavements. It was finally decided that Adderley, Parliament and Darling Streets be paved with creosoted red deal, that Plein and St Georges Streets be paved with Jarrah or other Australian Hardwood, and that Long and Darling Streets be paved with asphalt. Some of these experimental surfacing are still under these roads and are often uncovered in present rehabilitation projects.

The paving of Adderley Street and Plein Street were finally completed by the City of Cape Town's own teams in 1908 [11], Adderley Street with creosoted red deal blocks (which are still under some portions of the road today) and Plein Street with Jarrah wood blocks. Long Street was paved with asphalt by the Neuchatel Asphalt Company and must have been amongst the first of the City's asphalt roads. The grades of the cross streets were too steep in places for asphalt and these were paved with small granite setts laid in concentric circles and grouted up with bituminous grout. That technique was called "Kleinpflaster" and it was noted for being much quieter under traffic than ordinary sett paving.

In 1908 it was reported that the macadam surface of Queen Victoria Street had become very uneven and it was decided to try an experimental resurfacing technique called "tar-matrix" which was probably one of the first premix type resurfacing operations in Cape Town. The cost of resurfacing in tar-matrix was reported at 3 shillings 4 pence (3s. 4d.) per square yard compared with 2s. 6d. for casing in macadam.

Another surfacing method experimented with in 1908 was the use of asphalt blocks which were 50 mm (2 inches) thick and 254 mm (10 inches) square and were being supplied to the City by Standard Asphalte at a cost of 14s. 3d., delivered to site, per square yard. A section of Darling Street was paved with these blocks.

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“Tar painting” of macadamised roads was also becoming popular. It was described that a tar dressing was applied when it became necessary for a street to be re-cased throughout. It was reported in the Mayoral Minute in 1909 [11] that:

*“ It is impossible, as yet to say anything from our own experience, as to the value of this treatment in increasing the durability of the road surface, but there can be no doubt that it will be an important ally in the fight against the dust nuisance.”*

It was later reported that the tar paint on streets was being rapidly ground up in wet weather and that the streets that were treated with tar during the process of re-casing with macadam were standing up much better, probably because the tar had a chance to harden before being trafficked. Many of the City’s streets were rehabilitated using this method in the next couple of years. The wood paved streets were also causing problems due to the rapid expansion of the blocks during certain climatic conditions. It was also noted that the roads paved with cobbles, granite or asphalt were giving the least trouble.

A report was submitted by the City Engineer in 1915 detailing a trial section of bituminous surfacing on an old macadam roadway [11]. The trial section was laid in Shortmarket Street from St George’s Street to Greenmarket Square and was composed of Kloof Granite chippings, 6.4 mm (¼ inch) to 12.7 mm (½ inch) in size, which were heated and mixed with 87 litres (19 gallons) of pure Ebano bitumen to the cube yard of stone. The mix was laid hot, 76 mm (3 inches) thick and compacted by rolling with a 6-ton steam roller until compressed to a layer of 51 mm (2 inches) thick. Two hundred and nineteen square metres were covered at a total cost of £5 18s. 1d.

### 2.3.2 Towards the present (1920 to the present)

In Cape Town, in 1923 there were 407 kilometres of adopted roads, of which 97 kilometres were classified as main roads, and 92 kilometres of unadopted roads (roads which the City had not taken over) [11]. The roads were reported to be in a very poor state and a programme of reconstruction was proposed. The City Engineer reported that:

*“With the great increase in road transport generally, and particularly in the portion of self-propelled vehicles, it has become essential to abandon rough-and-ready rules and to adopt more scientific methods.”* [11].

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The first detailed traffic census was undertaken in preparation for a major rehabilitation exercise. The traffic in the survey was represented by the number of tons passing over a yard width of carriageway per hour. Figures ranged from 55 tons in part of Adderley Street to 7 tons in Bree Street, Kloof Street and Kooberg Road. A new traffic pavement classification was adopted based on traffic loading and was as follows:

Traffic Class	Depth of asphalt paving (inches)	Traffic record (tons per yard width)	Annual cost (per sq. yard of macadam)	Annual cost (per sq. yard if re-paved)
A	3	> 13	> 13 d.	about 6d. or over
B	2	9 to 13	9d. to 13d	about 5d.
C	1 ½	7 to 9	7d. to 9d	about 4d.
D	Not required	< 7	< 7d.	

Table 2.1: Pavement classification in Cape Town, 1922 [6]

It was reported that with the exception of a few roads in the City centre, all the main roads were constructed in waterbound macadam with unsuitable stone and generally without any foundations. The first pavement survey was done by the City of Cape Town in 1923 and was used as a tool for identifying reconstruction projects. A list of the roads surveyed is contained in **Appendix 2**. This information is very useful for future projects as many of these pavement structures are still in place today. **Appendix 3** contains information on materials used on roads and footways and outputs from municipal quarries. This information is of considerable use to identify materials that are uncovered in future projects. [The information comes from the Mayoral Minute of 1923]

The type of road surface recommended for the reconstruction scheme of 1923 was asphalt macadam laid on top of the old waterbound (where in satisfactory condition). The thickness of the layer was to vary from 38 mm to 76 mm (1½ to 3 inches), depending on the volume of traffic. It was further recommended that roads with exceptionally heavy traffic should be given a surface of small granite setts but that traffic noise on this surface could be a problem, but that this could be ameliorated by applying a thin asphalt coating. The reconstruction of 24 main roads was approved at an estimated cost of £ 256,494.00. By 1929 the project was completed and more than 48 kilometres of road had been reconstructed. A list of the roads and pavement structures is given in **Appendix 4**.

By the 1930's the many quarries in the City Bowl supplying shale, granite and sandstone had shut down due to environmental concerns. The City was then extensively using granite from the Brackenfell Quarry. In 1931 the total output from all quarries was 58 268 m<sup>3</sup>, of which 70% was coming from Brackenfell [11].

The granite produced at Brackenfell was described as having a much finer grain than the Cape Town granites, approaching the texture of the Paarl granite but not having quite as even a distribution of constituent crystals. Generally the finer the texture, the better suited the granite is for road construction material.

The City Engineer reported the following description of the stone on 12 May 1936 [4]: See also Table 2.2 which shows some of the properties as reported in 1936

*"The analysis of Brackenfell stone as set out hereunder, made by Mr C. H. Forrest, Chemical Engineer, London, indicates a definite deficiency in toughness, inferring a probability of the stone crushing readily under the roller or by subsequent traffic impact.*

*The stone, however, crushes nicely in cubelike form and binds well. This deficiency in toughness has been confirmed by observation in its practical use in road construction but not to a serious extent. Rolling, however, has to be done judiciously. It has been found that in road surfaces chipped with Brackenfell granite, the chippings are more readily crushed and dispersed than in those chipped with Hume quarry or Devils Peak quarry bluestone, which is a form of the Malmesbury shale series called hornfels. This action more or less only produces a semi-mosaic effect temporarily, until the lower bitumen is drawn up, and is generally desirable in penetration work. However, if it is proposed to use fine stone in premix wearing carpets it would be necessary to consider the employment of a tougher stone for these smalls."*

Property	Brackenfell stone	Standard
Specific gravity	2.63	2.65
Toughness	8.67	14.00-19.00
Dorry hardness	18.83	17.00
Abrasion French coefficient	14.00	14.00
Percent wear	2.85	3.50

Table 2.2: Properties of Brackenfell granite [4]

Many of Cape Town's roads were reconstructed with granite aggregate during this period and two examples that were investigated in 1936 are described below [4].

**Rosmead Avenue, Wynberg:** In 1936 this road was failing and was pockmarked where soft areas had eroded. It was concluded that the road was badly constructed because the granite hardcore had been too liberally blinded with fines and clayey gravel.

**Clive Street, Cape Town:** constructed in 1925 with a 38 mm (1½ inches) premix carpet composed of 19 mm (¾ inch) Brackenfell chips placed on top of the old cobbled surface. The surface was in good condition after 11 years of heavy traffic.

In the 1930's ferricrete was being replaced by bituminous macadam as the choice wearing course material. The ferricretes still in use were described as being too fine and clayey, giving off red dust in summer and becoming slushy in winter. Limestone was cheaper for gravel roads, but became knobbly after wear and in summer gave off a white dust which then formed a paste in winter that adhered to pedestrians boots creating a mess.

Economy of road construction was being debated and in 1936, the cheapest successful carriageway constructed was in Mayfield Avenue in Rondebosch. The road was constructed with a 64 mm (2½ inches) bituminously penetrated carpet on a limestone foundation with dished concrete surface channels. This was costed at 17s. per foot run [4].

Concrete roads were also being considered. Dagenham Road was constructed with concrete but the method was later abandoned in favour of bituminous surfaces. However, more than 50 kilometres of concrete road were constructed in the 1950's and 60's in Guguletu and other Cape Flats townships. They consisted of 150 to 250 mm mass concrete slabs laid directly on the subgrade. Many of the very steep roads in Sea Point, Fresnaye and the City Bowl were also constructed out of concrete due to the obvious problems associated with laying asphalt on very steep grades (greater than 15%). The concrete was rough broomed, unreinforced and 120 mm thick. During 1928, St Andrews Road in Rondebosch was constructed out of concrete, 175 mm thick and lightly reinforced, laid in two coats of different mixtures and surface treated with silicate of soda. The cost was 13s. 9d. per square yard [4].

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The methods and costs of road construction in 1936 were as follows [4]:

**Light traffic side streets:**

64 mm - 76 mm (2½ - 3 inches) bituminously penetrated carpet (or premix tar macadam large stone )  
152 mm (6 inches) hardcore foundation.

64 mm wearing course at 3s. 9d. per square yard.  
152 mm hardcore foundation at 2s. per square yard.

An alternative suggested was a 25 mm (1 inch) veneer course of premix on a 152 mm (6 inches) limestone base. The veneer costing 2s. 2d. per square yard and the base 2s. per square yard.

**Medium traffic link roads:**

76 mm - 102 mm (3 - 4 inches) bituminously penetrated macadam carpet  
229 mm (9 inches) hardcore foundation.

102 mm wearing course costing 4s. 6d. per square yard.  
229 mm base costing 2s. 9d. per square yard which was graded with a light waterbound macadam to receive the carpet.

The alternative for this class of road was a 76 mm (3 inches) two-layer premix carpet on a 229 mm (9 inches) hard core foundation. These cost 4s. 9d. and 2s. 6d. respectively and 1s. 3d. for the waterbound macadam.

**The specification for penetrated macadam wearing course was:**

Stone: 38 mm - 64 mm (1½ to 2 inches)  
Bitumen: 80 - 100 penetration at 2.3 to 4.5 litres (½ to 1 gallon) per square yard.

Seal coat with 13 mm to 19 mm (½ inch to ¾ inch) chips and 200 penetration bitumen at 1.1 to 2.3 litres (¼ to ½ gallon) per sq yard.

Included in Appendix 5 is a copy of the original drawings showing the various road pavement structures in use during this period.

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The Divisional Council were experimenting with a graded asphalt premix wearing course with the following specification:

Constituent	Proportion
Stone: 16 mm to 25 mm (5/8 to 1 inch)	45%
Stone: 13 mm to 16 mm (½ to 5/8 inch)	45%
Heavy flux C.B.	2.5%
T. R. asphalt	3.5%
Stone dust: 1.5 mm - 0.5 mm (1/16 inch to 1/500 inch)	4.0%
Net bitumen content	4.2%

**Table 2.3: Divisional Council wearing course specification 1936 [4]**

In 1937 the City Engineer reported [3] that a recent survey of road construction techniques revealed that there was a consensus of engineering opinion in favour of the premix (machine mixed stone and bitumen) type of surface and that this form of construction was rapidly replacing the bitumen grouted method (bitumen applied direct to stone forming road the surface). The bitumen grouted method was greatly favoured in the 1920's, where it was extensively used on the roads reconstruction project, as it required no special plant

The principal reasons stated for abandoning this method in favour of premix were as follows:

- Better riding qualities of the finished surface.
- More uniformity and intimacy in the mixture of materials with better prospects of longer life and reduced maintenance costs of the surface.
- The advantage of scientific control of proportions of mixture permitting saving on the bituminous components.
- Reduction in thickness of road surface for estate roads.

The City Engineer further stated that it is not unreasonable to anticipate the life of a 38 mm (1½ inches) premixed wearing course for suburban work at 20 years. The advantages of premix were appreciated for some time but it was only at this stage that the crushing plant became available at the Brackenfell quarry to produce the required graded crushed stone. A comparison of costs is reproduced in **Appendix 6**.

In March 1941, the City's premix plant in Ndabeni came into production and began supplying the following products: Bitumen binder, 19 mm ( $\frac{3}{4}$  inch) wearing course, 13 mm ( $\frac{1}{2}$  inch) wearing course, 9.5 mm ( $\frac{3}{8}$  inch) footway mix and sandmix [11].

In the 1950's Cape Town's freeway network was well under construction. The N1, N2, De Waal Drive, and many of the other City freeways were constructed with the following pavement specification [7]:

25 mm premix wearing course
50 mm premix binder course
76 mm waterbound macadam
180 mm gravel
280 mm compacted filling

The average cost of this structure in 1955 was £14 per foot run for a 30 metre carriageway.

By the 1950's and 60's, Cape Town's road construction programme was peaking and increased production had led to mechanisation of construction methods. Crushed stone, laterite and bitumen bases became the materials of choice as they were well suited for mass production and mechanised construction techniques. Continuously graded asphalt became the choice surfacing material. These materials are still used for the majority of road construction projects today.

## 2.4 Conclusions

This chapter has provided information on the type of materials and methods of construction used in the past. It is these pavement structures that are now requiring reconstruction and this historical information is required for the reconstruction design process.

The next chapter presents an overview of the geological aspects of the greater Cape Town area. This overview is needed to understand the behaviour of the underlying soils and the selection and performance of pavement materials.

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## **Chapter 3: Geological Perspective**

The performance of road structures is significantly influenced by the underlying geology, climate and the geological characteristics of the materials used. An understanding of these characteristics is essential to appreciate the road deterioration modes and rehabilitation design approaches. Rehabilitation engineering is heavily reliant on materials characteristics and a thorough understanding of their origin, properties and availability is required.

The first section of this chapter gives an overview of the geology of the Cape Peninsula by examining the different types of geological formations and their occurrence on the Cape Peninsula. The second section looks at the types of materials available, their characteristics and availability. It provides an essential background to the application of rehabilitation engineering in the Western Cape. [Acknowledgement is given to references 15 and 17 which comprehensively cover this subject and have been used as the basis for this chapter.]

### **3.1 General**

The major topographical features of the Western Cape consist of the Cape Peninsula, the Cape Flats and the Cape fold mountains towards the interior. The Cape Peninsula is flanked by the Atlantic Ocean on the one side and False Bay on the other with the Table Mountain chain forming a spine down the centre of the Peninsula. Table Mountain is the highest feature in the chain with a maximum height of 1086 m at Maclear's Beacon. The Cape Flats is a low-lying isthmus that connects the Peninsula to the interior and is covered mainly with dune sand, it is bordered by Table Bay to the north and False Bay to the south.

Cape Town has a Mediterranean type climate with hot dry summers and cool rainy winters. Because of the topography, there is a vast range of mean annual rainfalls. Areas on the Cape Flats average 500 - 700 mm per annum while some areas on the leeward sides of the mountains record as much as 1500 mm per annum.

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## 3.2 Geological formations

The area is generally comprised of:

- The Malmesbury Group
- The Cape Granite Suite
- The Cape Supergroup
- Surface deposits
- Pedogenic materials

Table 3.1 shows the geological period, origin and composition of these groups and provides a quick reference guide to associate materials with their geological groupings.

Figure 3.1 is a map of the Peninsula showing the location of these formations.

Each of the geological groups are examined in detail in the following subsections.

### 3.2.1 The Malmesbury Group

The Malmesbury Group is present over a large part of the area but is mostly covered by surface deposits. The group is exposed on the surface at the northern end of the Peninsula, forming Signal Hill and the base of Devils Peak. Good examples of the group appear along the coast from Sea Point to Granger Bay. It also forms the hills northeast of Cape Town in the Tygerberg area and underlies a large part of the Cape Flats and the Central Business District. These strata are called the Tygerberg Formation.

The predominant rock types in the group are grey to green phyllitic shale, siltstone and medium to fine-grained greywacke. These rocks are featured in irregular alternations. There are also a few thin layers of lava, pyroclastics, quartzite and conglomerate. The strata of the formation either dip steeply or are near vertical and are tightly folded about a NW - SE oriented axes.

The quartzitic greywacke is dark grey and is formed in massive layers, up to three metres thick, from near the Alfred Basin through to the Sea Point Swimming Pool. Fresh outcrops can be seen in the quarries on Signal Hill and Devils Peak.

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Age (millions of years)	Period	Lithostratigraphy			Origin	Description
0.001	Recent				Pedogenic	Calcrete, silcrete, ferricrete
					Colluvial	Transported boulders, gravel and sands
3	Quaternary	Cape Flats Formation			Alluvial	Transported sand, silt and clay, peat
					Aeolian	
					Marine	
150 - 190	Jurassic	Karoo Sequence				Intrusive dolerite dykes
400 - 450	Silurian				Pakhuis Formation	Diamictite
	Ordovician	Cape Supergroup	Table Mountain Group	Peninsula Sandstone Formation	Graafwater Sandstone Formation	Thinly bedded quartzitic sandstones. Very minor shales Thin - bedded sandstones, shales
	Erathem					
610	Namibian	Cape Granite Suite	Cape Peninsula Pluton			Course - grained granite
650 - 700		Malmesbury Group	Tygerberg Formation			Greywacke, hornfels, phyllite, mudstone, shale, slate and minor volcanics

Table 3.1: Geology of the Cape Peninsula [15]

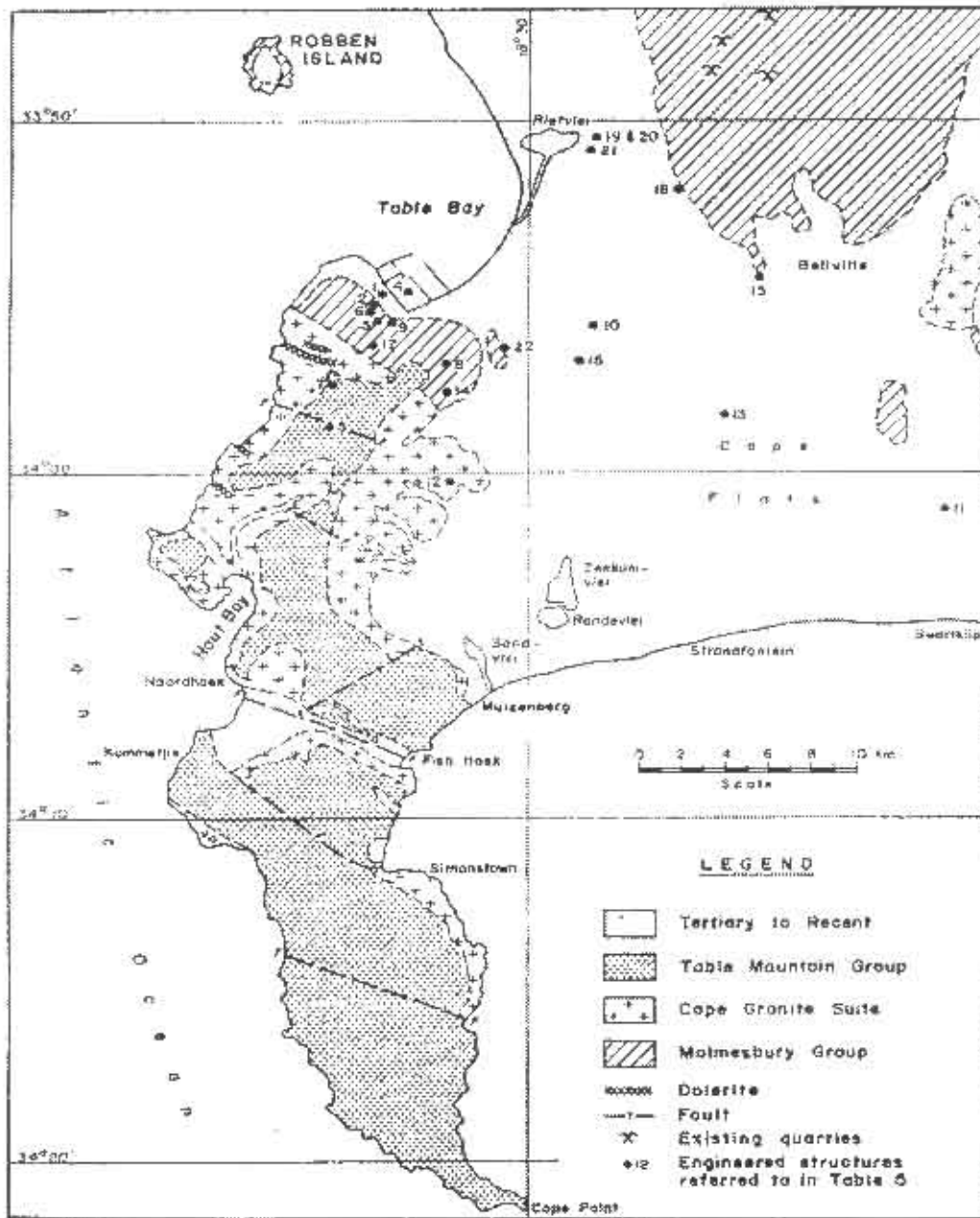


Figure 3.1: Geology of the Cape Peninsula [15]

### 3.2.2 The Cape Granite Suite

The Cape Granite Suite is split into the Cape Peninsula Pluton and the Kuils River-Helderberg Pluton. The Cape Peninsula Pluton occurs to the south of the Malmesbury Group and underlies the Table Mountain Group.

The granites are exposed in numerous outcrops along the Peninsula coastline from Sea Point to Chapman's Bay, from Simonstown to Smitswinkelbaai and at Cape Point. There are a few granite outcrops rising above the Cape Flats. The outcrops on the mountain slopes are mostly deeply weathered consisting of large rounded boulders.

The pluton comprises grey coarse-grained biotite granite with large feldspar phenocrysts. There are also metamorphosed Malmesbury inclusions and clots present in the granite. Various other varieties of granite occur in the suite and the pluton is crossed by aplite and pegmatite dykes.

### 3.2.3 The Cape Supergroup

Referred to as the Table Mountain Group, this consists of the Graafwater, Peninsula and Pakhuis Formations. Each of these is summarised below.

#### *The Graafwater Formation*

This formation consists of reddish, thin bedded sandstone shales and is situated at the base of the Peninsula Sandstone Formation. The sedimentary rocks of the Table Mountain Group were deposited on the granite and other pre-Cape rocks. A good example of the contact between the Graafwater Formation and the granite can be seen along Chapman's Peak Drive. The Graafwater-Malmesbury contact can be seen on Table Mountain Road between Vredehoek and the Kings Blockhouse.

#### *The Peninsula Formation*

The formation consists of a uniform light-grey, medium to coarse grained quartzitic sandstone which is consistently well bedded and nearly horizontal. The horizontal beds are clearly visible on the middle and upper portions of the Table Mountain Range and reach a maximum thickness of 600 m at Maclear's Beacon. The depth of the individual bedded strata range from thin to massive (50 mm to 1.4 m) and alternate with one another. The front face of Table Mountain is an impressive example of the formation.

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### ***The Pakhuis Formation***

This formation occurs only in a few places on the summit of Table Mountain. It consists of diamictite of mixed alluvial and glacial origin. It is a sandstone containing rounded quartz, quartzite and black chert pebbles. The massively bedded diamictite averages two metres in thickness and rests on the Peninsula Formation.

### **3.2.4 Surface Deposits**

There are several different types of surface deposits on the Cape Peninsula and these are detailed below.

#### ***Alluvium***

Alluvial deposits border all the river courses, they vary in thickness and consist largely of dark coloured organic sand. Five metres thick deposits have been noted in some building foundations. The deposits are not clearly defined and merge into light grey, sandy soils.

#### ***Scree and pediment gravel***

The Peninsula mountain chain is fringed by extensive mountain scree deposits that grade marginally into pediment gravel and coarse-grained sand. The gravel consists of angular sandstone blocks with interstitial gravel and sand. The blocks vary in size from centimetres to a few metres. Granite rocks are also often present in various sizes. This gravel can exceed ten metres in thickness and it covers the Table Mountain sandstone, Malmesbury shale and granites.

#### ***Shell bearing dune sand***

All along the coastline there is a fine to coarse grained, light grey sand which has a fairly high percentage of shell fragments. The silica grains have a high degree of rounding and are sometimes coarse or finely graded due to the prevailing wind. In places extensive sand has accumulated into parabolic dunes up to 82 m above sea level. The dunes have a predominantly north westerly orientation because of the prevailing south easterly winds on the south facing sandy beaches during the dry summer months. The extensive dunes on the Cape Flats probably also originated from the south easterly winds at the time of the last ice age, about 17 000 years ago, when the sea level was lower exposing additional sand. Variations in the concentrations of shell fragments frequently result in partial cementation due to high concentrations of CaCO<sub>3</sub>.

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### ***Light grey sand soil***

Large areas of the Cape Flats are covered with a light grey to pale red sand. The deposits consist of interwoven sandstone lenses which are mostly older than the dune sand. Thin clay lenses occur randomly. Peat lenses up to six metres thick are common and sometimes contain sulphide nodules.

A maximum thickness of 32 metres is reached south of Philippi, farther north and east the succession decreases to a thickness of around 15 metres and contains many clay and conglomerate lenses and thin layers of ferricrete. To the south the soil varies in thickness and is 20 metres thick in the Strandfontein-Mitchells Plain area. East of Strandfontein it generally overlies Malmesbury rocks while in the west towards Muizenberg it is found over granite.

### ***Other soil varieties***

The soil formed on the Malmesbury rocks is yellow, red or brown. It often contains small nodules of ferricrete and fragments of vein quartz plus sand grains. The soil is clayey and can have a high plasticity index. The soil appears on the surface in the Tygerberg area as a relatively thin cover. In some places there are partly cemented layers containing ferricrete.

A brown clay soil, not more than 300 mm thick, containing impure gypsum crystals, is found at one to two metres above sea level in Rietvlei and along the lower courses of the Diep River. Similar clay soil is found bordering the Hout Bay River and the upper parts of the Keyser and Diep Rivers. These deposits are less clayey than in Rietvlei and can be several metres thick.

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### 3.2.5 Pedogenic materials

Pedogenic materials are formed when minerals, precipitated by water movement, relace or cement the original soil. Pedogenic materials occur all over the Peninsula and the three types are detailed below.

#### *Ferricrete*

Ferricrete occurs mainly in transported soils overlying the Malmesbury Group but is also found in the colluvial soils overlying the Granite and Table Mountain Groups. Ferricretes are associated with seepage areas and all of the deposits have formed near the surface by the ground water depositing concentrations of iron oxide derived from the underlying weathered rocks.

Ferricrete occurs in the Peninsula near Simonstown, Kommetjie, north of Ysterplaat, Tableview, Tygerberg and Durbanville. The ferricrete can occur as loose nodules which range in size from a few millimetres to several centimetres in diameter, or as compact zones of variable thickness. The deposits at Plattekloof and De Grendel are in the form of a hard-dark brown, knobby rock which often contains friable parts with honeycomb texture. The deposits are up to a metre thick. Other deposits (north of Killarney and near Durbanville) consist of an amorphous friable mass of ferruginised nodules, sand, clay and quartz chips, cemented by iron oxide. Deposits on the Peninsula are similar but also contain many fragments of quartzite.

#### *Calcrete and limestone*

Calcrete occurs extensively on the Cape Flats and achieves maximum development between Strandfontein and Macassar. Most of the deposits occur as massive, grey, sandy surface limestone. Well bedded sandy limestone and friable, partly cemented calcareous sand occurs near Swartklip, Zeekoevlei, north of Bloubergstand and on Robben Island. The massive surface deposits are in the form of large irregular banks which are mostly covered by aeolian sand. In the valleys between dunes, the lime beds are usually within a metre of the surface. The banks consist of several hard well cemented layers which alternate with softer clayey or crumbly lime rich zones. The degree of cementation and thickness of the calcrete varies considerably and can exceed ten metres. Most of the deposits are only a few metres thick, consisting of an upper, hard, densely cemented zone, of about 300 mm thick. This rests on soft, sandy yellow calcrete which grades into calcareous sand.

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### *Silcrete*

Silcrete occurs mainly in the north eastern suburbs and always near weathered Malmesbury rocks. The most extensive outcrops are in the vicinity of Phesantekraal where the silcrete forms a cliff several metres high. The surface outcrops consist of hard rock that weathers into massive, smooth, partly rounded blocks. The degree of silicification decreases with depth and eventually grades into partly consolidated material. The silcrete varies from yellow to light grey and course to fine grained.

## **3.3 Construction materials in the Western Cape**

The reconstruction or rehabilitation process requires reusing existing materials or importing new material. It is therefore necessary to know what materials are available and where they are located. This section explores the different types of construction materials based on their geological grouping.

### **3.3.1 Rock material**

Available rock materials are described below according to their geological grouping.

#### **Malmesbury Group**

The main rock types used, are metamorphosed greywacke, slates and hornfels which are collectively referred to as Malmesbury shale. Malmesbury shale provides most of the crushed rock aggregate used in the Cape Town area. On the slopes of Signal Hill and Devils Peak there are the remains of at least sixteen hornfels quarries. The Kloof Quarry, Reids Quarry, Smits Quarry, Strand Street Quarry and Wylies Siding are the best known. Presently quarries are operating in the Tygerberg Hills, Eerste Rivier and near Sir Lowry's Pass.

Crushed Malmesbury shale is widely used in road construction as base course, subbase and as aggregate for concrete and asphalt. Good quality hornfels aggregate is derived from dense fine-grained rock that breaks into irregular angular fragments. Flakiness is sometimes a problem in the production of asphalts. Alkali-aggregate reaction is also a serious problem in the production of concrete. This is caused by a reaction between high alkali cement and Malmesbury group aggregates which produces a gel. Cracking occurs due to the swelling pressure of the gel and many of Cape Town's concrete roads exhibit various degrees of cracking due this process. The problem is overcome by specifying low alkali cement.

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### **Cape Granite Suite**

Granite was extensively used as basecourse up to about the middle of the twentieth century when the Kloof Nek granite quarry and the Brackenfell quarry were closed because of residential development in the vicinity. Sources are still available in Paarl and Saldanha Bay but are not presently used for road construction. The granite was mostly used as stone in macadam penetration bases.

Granite was also extensively used as dimension stone and many of Cape Town's older buildings are constructed from granite blocks. Most of the older roads in the Cape Town area used granite blocks for kerb and channel units. A report to the City Engineer in 1936, when granite from Brackenfell was still extensively used as base course, remarked on a deficiency in toughness and expressed concern about the stone crushing under compaction and cautioned on its use as an aggregate for premix.

### **Table Mountain Sandstone**

No local quarries are currently producing sandstone but it was used as road aggregate in the early twentieth century. It was used extensively in the southern parts of the Peninsula where it was quarried at Chapman's Peak and Glencairn. Sandstone was also used for kerb and channel units on some of the older roads.

When in use as road aggregate in the 1940's the Chapman's Peak stone was described as a fine-grained purple sandstone with an argillaceous cement and the Glencairn rock as a very pure grey or green quartzite. Both rocks being interbedded with layers of soft shale which negatively affected its performance as a road aggregate.

#### **3.3.2 Residual soils**

Brick producers used decomposed mudrocks of the Tygerberg formation occurring in the Salt River and Mowbray areas. However, these workings have been closed down due to their proximity to residential areas. Clays are mined in the Brackenfell area from the Malmesbury and derivative rocks.

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Weathered granite has been used in road construction and completely weathered granite, called kaolin, is mined in the Fish Hoek-Noordhoek area for the production of ceramics.

Weathered sandstone, from fractured faults in the rock mass, has been used for road construction in the Fish Hoek area.

### **3.3.3 Pedogenic material**

The two different types of occurring pedogenic materials are described below. Silcrete is rarely used.

#### *Ferricrete*

Ferricrete natural gravel deposits are found in the soils on top of the Malmesbury Group. These deposits occur on the lower slopes of relief hills near Durbanville and are covered by a mantle of predominantly sandy soil. The deposits are relatively thin and most have been worked out. The material has been used in the construction of gravel roads and as base and subbase for surfaced roads. Ferricretes overlying granite tend to have a patchy development. Ferricrete overlying Table Mountain group strata is common and has been quarried at Noordhoek and in the Cape Point Nature Reserve.

The quality of ferricretes can vary considerably with depth and careful control of the plasticity index (PI) and CBR of the material is required. Some ferricretes may be located far away from the original source of iron oxides and these deposits may have very low PI's. Segregation during mixing on the road surface can be a problem because of the material grading and the rounded shape of some ferricretes. Most ferricretes will re-cement if exposed to wetting and drying cycles which can result in considerable strength gain over time and old road basecourses can attain insitu CBR values of well above 100.

#### *Calcrete*

Calcrete has been used as base course and subbase, mostly in lower class residential roads in the southern part of the Peninsula as most of the reserves are located in this area. The quality of the material varies considerably and the plasticity index, CBR and grading of the material needs to be very carefully monitored. The material is susceptible to high moisture content and its performance in Cape Town's roads has often been disappointing, this probably due to lack of proper quality control. Calcrete is also used as a source of lime in the cement industry.

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### 3.3.4 Cape Flats sand

The Cape Flats sands are mostly only suitable for use as fill in the road construction industry. The sand consists of a mixture of marine, alluvial and aeolian sands. Some of the deposits are silty to clayey but most have a very low plasticity index. The sands are found deposited in the dune systems of the Western Cape and are extensively mined as a source of concrete sand and fill. The main source area is near Philippi where several sand mines are currently operating. The sand has a single sized grading. The finer fraction of sand has been removed by wind action. Water leaching has removed the shell fragments which reduce concrete strength. The dune sand is mostly non plastic and is an excellent source of road fill material.

## 3.4 Conclusions

There are a variety of different geological features in the Western Cape and it is important to be able to recognise them and know where they occur as they each require different rehabilitation design approaches. Various construction materials result from the geological features and each have their own characteristics and specific uses in reconstruction projects.

Table 3.2, below, gives a useful summary of the different materials and can be used as a quick reference guide for the Engineer.

---

Type of Material	Geological origin	Description	Use
Pedogenic materials	Recent	Ferricrete	Gravels for all types of road construction
		Calcrete	Gravels for road subbase and base if good quality, manufacturing of cement
		Silcrete	Rarely used
Transported materials	Tertiary to recent sand	Cape Flats sand	Fine aggregate for concrete, asphalt filler, fill
	Table Mountain Group	Talus, alluvial, colluvial, sand	Processed gravels for concrete, road aggregate
	Cape Granite Suite	Clayey grits and gravels	Gravels for road subbase and selected fill if good quality
	Malmesbury Group	Clays and silts	Rarely used
Residual materials	Table Mountain Group	Silty sand and residual gravel	Natural gravel for roads
	Cape Granite Suite	Clayey sands and residual granite	Subbase and gravel roads, selected fill
	Malmesbury Group	Clayey silts and residual gravels	Road gravel and fill
Rock	Table Mountain Group	Quartzitic sandstone	Concrete and road aggregate, building stone
	Cape Granite Suite	Granite	Concrete and road aggregate, building stone, railway ballast
	Malmesbury Group	Metasediments (hornfels): predominantly greywacke and slates	Concrete and road aggregate, railway ballast, breakwater rubble

Table 3.2: Types of construction material [15]

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**SECTION 2**

**SYSTEMS REQUIREMENTS**

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## **Chapter 4: Procedures for the selection and prioritisation for the rehabilitation and reconstruction of roads in Cape Town**

In the absence of published information on a systems approach for the selection and prioritisation of roads for rehabilitation and reconstruction within a metropolitan context, the Author developed the approach presented in this Chapter. However, much has been published on Pavement Management Systems and their uses [20, 21, 24 & 25]; this information provides some of the tools for the systems developed in this chapter.

All roads are subject to deterioration and thus have a limited useful life. Much of Cape Town's road network was constructed in the sixties and many roads are now approaching the end of their useful life.

When roads eventually reach the end of their useful life, rehabilitation or reconstruction procedures become necessary to prevent the road becoming a danger to traffic. Rehabilitation and reconstruction procedures are expensive and to ensure that optimum use is made of available funds a systematic approach has been developed by the Cape Town City Council's Roads Directorate to ensure that the correct roads are selected for the correct treatments.

A Pavement Management System is used for the initial selection of roads. Thereafter the reconstruction/rehabilitation process includes prioritisation, detailed investigation, design and construction. Figure 4.1 (p 30) demonstrates that the structural life of a pavement can be divided into three fairly distinct phases namely:

1. Commencement Phase
2. Service Phase
3. End Phase

It is the condition of the pavement that needs to be monitored in order to assess the structural state of a road. Various defects in the road pavement will manifest as the road ages through the different life cycle phases. These defects usually occur long before the road user is aware of any problem. The condition of the pavement can be quantified by observing the degree and extent of defects that are present in the road surface. These defects may be in the form of one or more of the following:

- cracks - of which there are numerous different types,
- deformations,
- potholes,
- polishing of stone in the surfacing,
- ravelling (loss of surface stone) and
- pumping of material through cracks

The road condition can thus be monitored by observing the type, degree, extent and spacing of these defects. The type of defect can also give clues as to what is causing the problem and consequently the type of treatment required. For example, if there is extensive crocodile cracking with pumping and deformations, this indicates that the pavement layers are failing. While ravelling and polishing indicate that the surface is failing.

The mechanisms causing these defects may be one or a combination of the following:

- Degradation of the pavement layers through the cumulative effects of traffic loading (wheel loads are critical in this respect).
  - Breakdown and loss of flexibility of the bitumen in the wearing course and/or basecourse caused by exposure to the elements (ultra violet radiation, temperature variation and rain).
  - Structural weakening of the pavement layers caused by the ingress of water. Water may enter through cracks in the surfacing or from the natural underground water table which rises during wet weather.
  - Subgrade materials that may expand or collapse during wet and drying cycles.
  - The action of moles digging burrows under the road causing collapses.
-

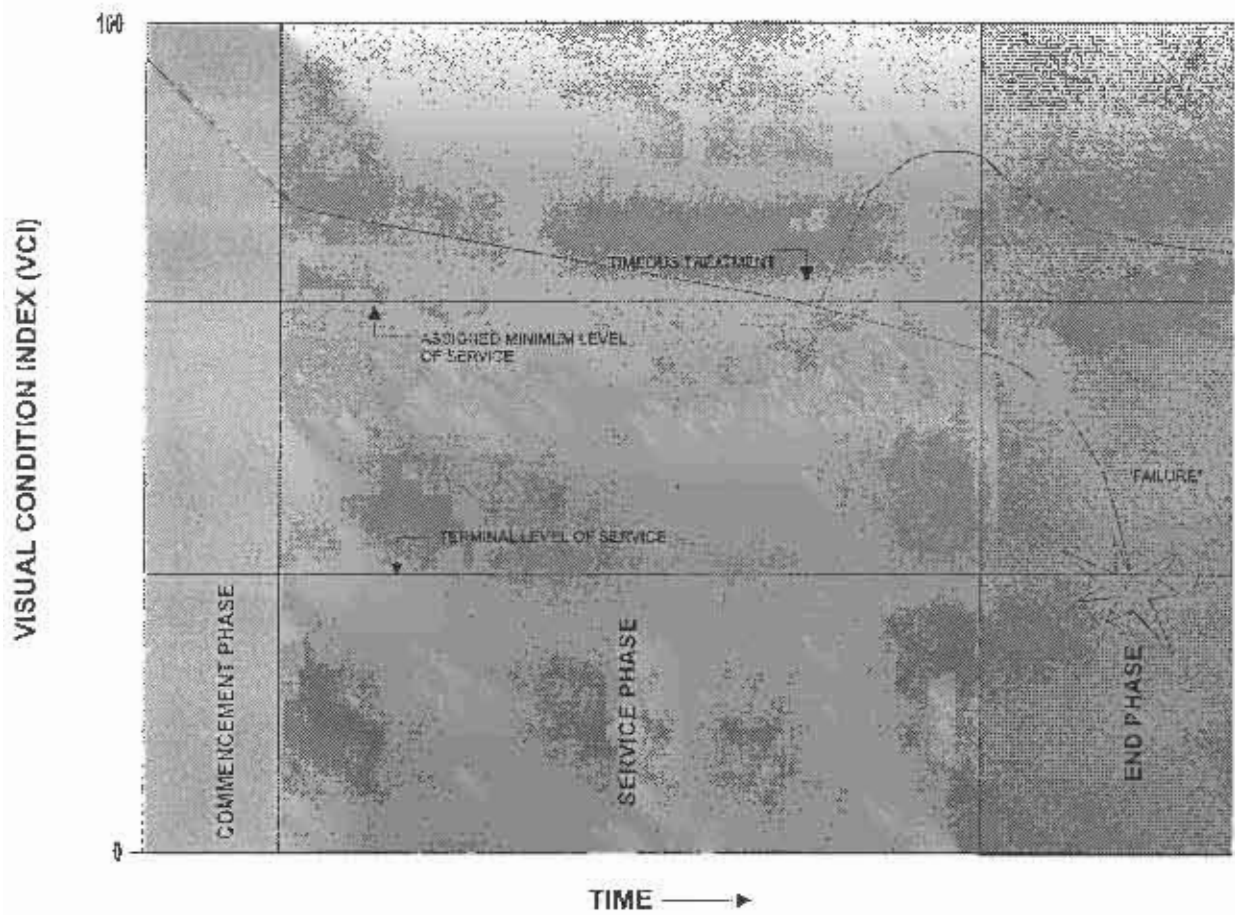


Figure 4.1: Schematic description of the Life of a road

#### 4.1 Pavement treatments

As the pavement deteriorates through these phases, various different treatments can be applied to extend its life. Table 4.1 shows typical treatment strategies that can be considered.

Type of treatment	Cost	Appropriate stage of life cycle for implementation
<p><b>Minor maintenance</b> e.g. pothole filling, crack sealing</p>	Cheap	Early phase of deterioration
<p><b>Resealing</b> e.g. slurry seal, chip and spray. This is a thin seal that is placed on top of the wearing course. Its purpose is to seal a cracked wearing course.</p>	Fairly cheap	Early phase of deterioration.
<p><b>Resurfacing</b> 25 mm to 40 mm Asphalt overlay. This is placed on top of the existing wearing course and its purpose is to seal a cracked wearing course and also to improve the riding quality and drainage by smoothing out surface deformations.</p>	Fairly cheap	Early to more advanced deterioration.
<p><b>Rehabilitation</b> Structural strength of pavement increased e.g. thick overlay, recycling of pavement layers. The purpose of rehabilitation is to improve the structural capacity of the pavement by making use of the existing pavement materials.</p>	Expensive	Advanced deterioration
<p><b>Reconstruction</b> Full replacement of pavement layers. The existing pavement materials have deteriorated to such an extent that they have to be replaced.</p>	Very expensive	Pavement at end phase

Table 4.1: Pavement rehabilitation strategies

## 4.2 Pavement Management System (PMS)

Pavement management systems were developed in the United States of America in the late 1970's and were implemented more widely in the 1980's. In 1984 the Metropolitan Transport Commission for the nine-county San Francisco Bay Area started a PMS which was amongst the first that was developed specifically for a city environment [23]. Cape Town developed and implemented its own system in the late 1980's which was based on the methods developed by the American Association of State Highway and Transportation Officials (AASHTO). In 1995 the Committee of State Road Authorities compiled the Draft TRH 22: Pavement Management Systems [25] which has become the excepted authority on this subject in South Africa. TRH 22 led to a second-generation system for Cape Town which was developed by a consortium called Peninsula Road Consult [22].

## 4.3 The Cape Town PMS

Determining the best maintenance strategy for a specific road is technically complex. It is important that the correct option be implemented at the right phase in the pavement's life cycle. This will ensure optimum use of available funds. The influence of timely treatment in increasing the life of a road can be seen by the dotted line on the graph in figure 4.1. Experience has shown that a satisfactory solution to this problem can only be made by making use of an objective evaluation of information about the condition of the whole road network which is collected systematically on a regular basis.

Procedures to assist in this function are collectively termed the 'Pavement Management System'. Road engineers worldwide have come to regard such a system as an essential planning and design tool. The PMS essentially consists of the following components:

### 4.3.1 Data collection

Every road segment in the network is ideally inspected once per year by a qualified inspector. The type, degree, extent and spacing of defects are scored on an inspection sheet. The scores for the different defects are weighted according to their severity and influence on the pavement's life cycle and various indices for each road can be calculated. An example inspection sheet is shown in Appendix 7.

The results of visual evaluations can be used to determine:

- the current pavement condition,
  - maintenance and rehabilitation needs and
  - priorities at network level.
-

Visible distress is an important input in the assessment of the condition of a pavement structure. However, other methods of condition assessment should also be used. Depending on the resources available, one or more of the following could be used:

- riding quality measurements,
- rut measurements,
- skid resistance measurements and
- deflection measurements.

#### 4.3.2 Data analysis

The following main outputs can be obtained by evaluating and processing the visual assessment data:

- i. A list of types of visual distress that occur on each assessment length, together with an indication of the severity and extent of occurrence.
- ii. A condition index for each assessment length through the combination of:
  - the rating for degree,
  - extent of each distress type and
  - a weighting factor based on the importance of distress type.

The condition index can be used to:

- give an indication of the condition of the pavement of each assessment segment,
  - indicate the change in the condition of a pavement over time,
  - classify the road into one of five condition categories (very good, good, fair, poor, very poor) and
  - prioritise maintenance and rehabilitation work.
- iii. Identification of required maintenance or rehabilitation needs and priorities.

The successive yearly scores for each road can be plotted graphically as shown in **figure 4.1** (the PMS score in the form of a visual condition index is on the vertical axes). It is then possible to deduce at what stage of its life cycle the road is at and to recommend timely and appropriate treatment. A further product of this graph is to ascertain the effectiveness of past treatments (see chapter 5).

---

### **4.3.3 Network analysis**

The state of the whole network can be analysed and budget requirements can then be set. An important output of the system is to determine the required amount of maintenance money to be spent each year to maintain the network at an appropriate level of service, as opposed to having large quantities of roads reaching the terminal stage simultaneously and then requiring massive capital expenditure on expensive reconstruction.

### **4.4 The identification of roads requiring rehabilitation and reconstruction**

Once the whole network has been inspected by the PMS, it is possible to categorise roads according to their condition and recommended treatment. Various indices are used in this process. The visual pavement condition data for individual distress types can be combined to form different indices as shown in figure 4.2. A general visual condition index is calculated by using all the visual data. Various other pavement indices, such as functional, surface, structural or maintenance condition indices, can be calculated based on certain select distress groupings.

Many different methods of calculating a visual index have been developed. The method used in Cape Town is based on the TRH 22 method which was developed by the Committee for Compatibility of Pavement Management Systems [25]. The Committee developed this system for South African conditions, after investigating all the available methods. The objective was to produce a method giving results that have a good correlation with the judgement of an expert panel of raters [25].

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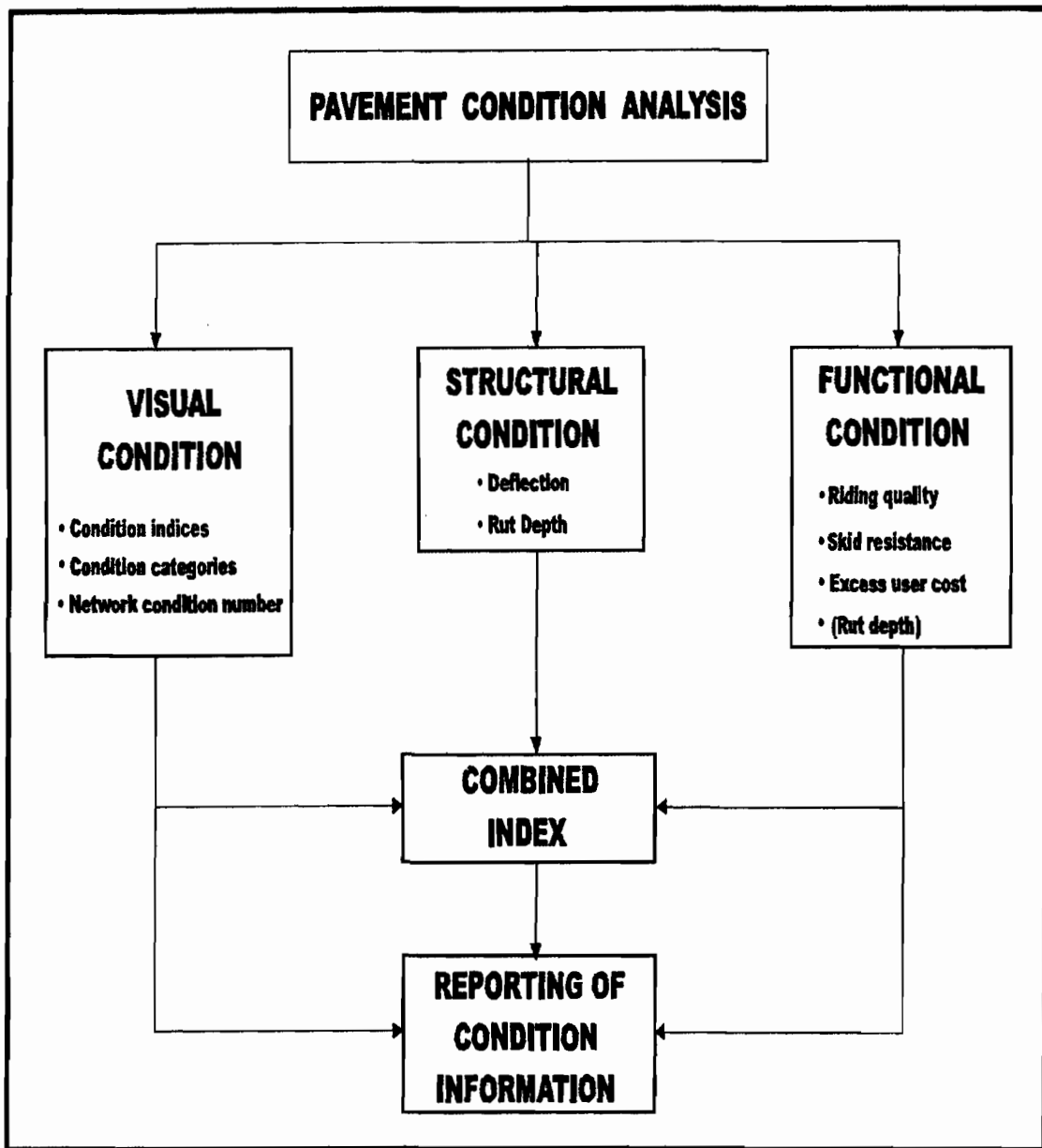


Figure 4.2: Pavement condition analysis [25]

The visual condition index (VCI) and the priority index (PI) are used to produce an initial list of roads to be considered for rehabilitation.

The VCI is calculated as follows [25]:

$$\mathbf{VCI_p = 100 \{ 1 - C * (\sum_{n=1}^N F_n) \}} \quad (4.1)$$

where:

$VCI_p$  = Preliminary visual condition index

$F_n$  =  $D_n * E_n * W_n$

$n$  = Visual assessment item number

$D_n$  = Degree rating of defect  $n$

(Range 0 to 4 for functional defects, 0 to 5 for other defects).

$E_n$  = Extent rating of defect  $n$ .

(Range default 3 for functional defects, 0 to 5 for other defects).

$W_n$  = Weight for defect  $n$

$C = 1 / \{ \sum_{n=1}^N F_n(\max) \}$

$F_n(\max) = F_n$  with degree and extent ratings set at maximum.

The  $VCI_p$  is transformed to a percentage scale using:

$$\mathbf{VCI = (0.02509VCI_p + 0.0007 VCI_p^2)} \quad (4.2)$$

The algorithm for the Priority index (PI) is as follows (developed by Peninsula Road Consult) [22]:

$$\mathbf{PI = \{(6 - D) + (5 - E) / 10\} * VCI * (f/100) * A} \quad (4.3)$$

Degree (D) and extent (E) will apply to the defect triggering an action.

The treatment PI is the highest PI of all the individual defects considered for a treatment. PI is trimmed to a value between 0 and 5, with two decimals.

Where :

$A = \min (0.5, B)$

$B =$  Suburb weight \* district weight \* climate weight \* traffic weight \* road category weight. Each of these weights depends on the network definition values for the link.

$f =$  constant entered on weights screen, same for all defects.

#### 4.5 Selection verification

Once per year the roads identified by the PMS for rehabilitation are inspected by the Road Coordination Team. This team consists of experienced engineers and technicians. The Team carefully inspects each road and consensus is reached in deciding whether the road goes on to the list of roads requiring detailed investigation towards rehabilitation or reconstruction, or whether cheaper resurfacing is still viable, in which case the road is grouped back into the 'poor' category and goes onto the annual resurfacing programme. The resulting list of roads requiring rehabilitation/reconstruction is then subjected to detailed investigation and design.

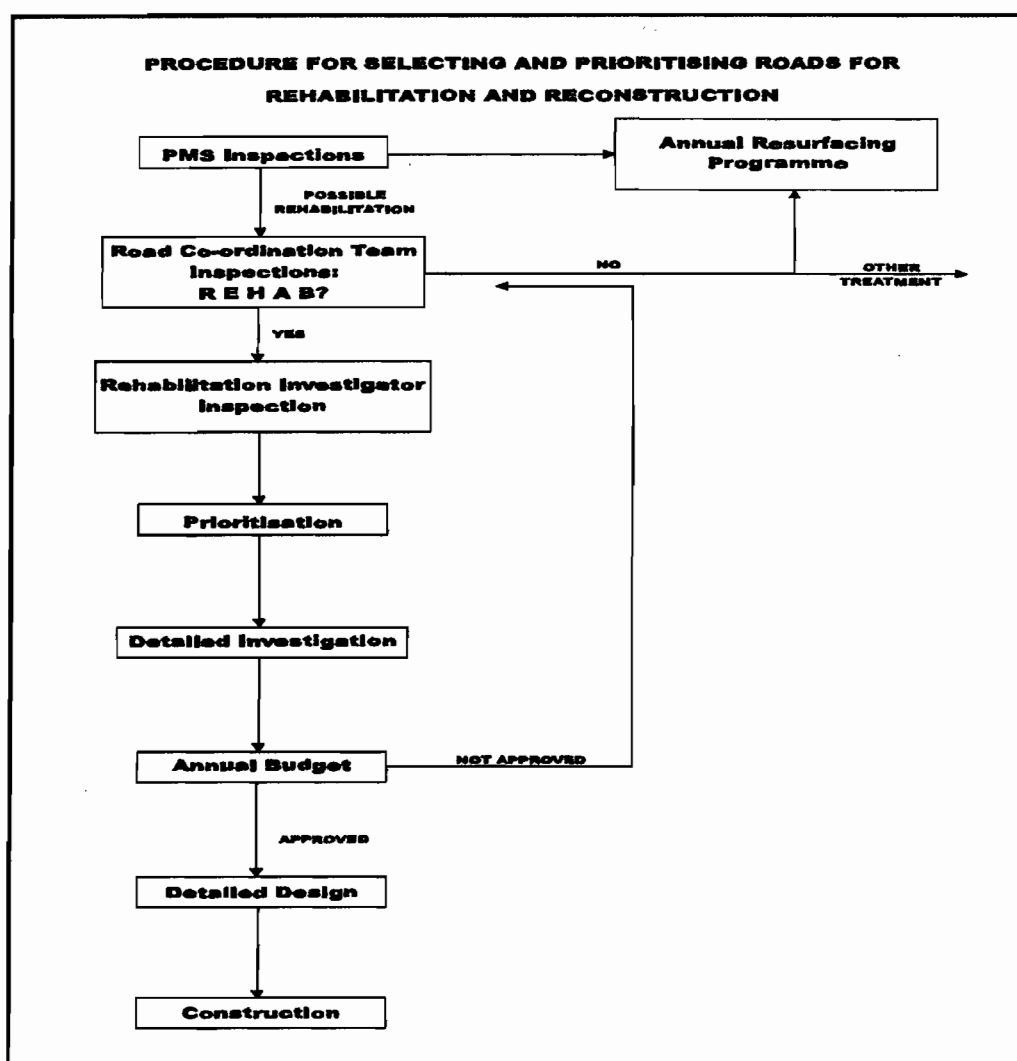


Figure 4.3: Procedure for selecting and prioritising roads

#### 4.6 The rehabilitation/reconstruction process

The roads identified for rehabilitation are then subjected to a process which will ultimately lead to the implementation of a maintenance solution. Figure 4.3 is a flow chart, developed by the Author, summarising the process.

#### 4.7 Prioritisation

The Pavement Management System produces a list of roads requiring rehabilitation. Because there are inevitably insufficient funds to implement all of the projects, a prioritisation system is required. In the absence of applicable literature, the Author has developed the method set out below:

Each road on the rehabilitation/reconstruction list is given a priority rating. This rating is based on the following criteria:

- **Condition of road.** The VCI is used to quantify the road condition.
  - **Traffic Class of Road.** The traffic class is defined as follows:
    - Category A: Freeways & major urban roads, e.g. N2, Table Bay Boulevard, Kromboom Parkway.
    - Category B: Urban collectors & major industrial roads, e.g. Gunners Circle, Kendal Road.
    - Category C: Lightly trafficked residential roads, e.g. Bath Street in Tamboerskloof.
  - **Serviceability survival time.** The length of time, with the execution of routine maintenance, that the road can remain usable before it disintegrates and becomes dangerous to traffic.
-

Each road is scored according to the table shown below:

CONDITION OF ROAD	VC I points	Value of coefficient A
	> 50	1
	40 - 50	2
	30 - 40	3
	20 - 30	4
0 - 20	5	
TRAFFIC CLASS OF ROAD	Class	Value of coefficient B
	A	5
	B	3
C	1	
SERVICEABILITY SURVIVAL TIME	Time	Value of coefficient C
	< 6 months	5
	6 - 12 months	4
	12 - 24 months	3
	24 - 36 months	2
> 36 months	1	

**Table 4.2. Road prioritisation scoring**

The roads are then prioritised according to the Rehabilitation Priority (RP):

$$RP_p = 4A + 3B + 2C \quad (4.4)$$

The weightings of 4, 3, 2 in the above formula have been established by calibrating with priorities that have been established by experts in the rehabilitation field.

This is converted to a score out of 100,

$$RP = 2RP_p / 9 \quad (4.5)$$

#### **4.8 Detailed investigation**

A detailed investigation of each road identified is carried out. The purpose of this investigation is to determine the pavement failure mechanisms and to recommend appropriate action. The investigation will usually consist of the following procedures:

- Detailed visual site investigation which entails mapping all the relevant failure features.
- Geological investigations.
- Trial holes are dug in appropriate places and the pavement profile recorded.
- Sampling of pavement layers and subgrade materials.
- Laboratory analysis of pavement and subgrade materials. CBR, Atterberg limits and gradings are initially most useful to determine the suitability of the material.
- The use of probes (e.g. DCP) to determine material bearing capacities and insitu densities.
- Deflection testing to determine stiffness moduli of the different layers.
- Water table investigations.
- Traffic counts.

#### **4.9 Choosing the appropriate treatment**

After the detailed investigation it is possible for the engineer to deduce the failure mechanisms and then recommend appropriate rehabilitation or reconstruction actions. There are many treatments available some of which are listed below:

- Thick structural overlays
- Cold milling and replacement of the wearing course
- Hot insitu recycling of the wearing course
- Cold insitu recycling of pavement layers
- Removal of pavement materials for recycling and replacing
- Reconstruction

#### **4.10 Design**

When the rehabilitation option is finalised, a design engineer will prepare the detailed construction drawings. If specialised rehabilitation techniques are proposed then it may be necessary to engage external consultants. For example, the design for the hot and cold insitu recycling requires specialist laboratory analysis which is not available Departmentally.

---

Components of the Detailed Design are listed below:

- Site survey
- Services investigation
- Pavement design
- Geometric design
- Detailed cost estimating
- Preparation of contract documents (as necessary)

#### **4.11 Budgeting and Programming**

The following factors need to be considered in order to make a realistic yearly budget allocation:

- **Importance:** Major roads and roads of importance that are no longer serviceable and if not treated will become a danger to traffic. These roads need immediate consideration.
- **Growth:** What is the growth of roads in the whole network requiring reconstruction? We need to at least spend enough each year so that the total requirement does not grow out of control.
- **Ranking:** The relative requirements and importance of other streetwork projects on the Capital Development programme within a limited budget.

#### **4.12 Conclusions**

A solution to the problem of optimising expenditure with requirements, can be achieved by following a systematic approach. This system flows from a network analysis, using a Pavement Management System, to the project selection level using prioritisation techniques. These procedures are informed by many changing variables (budgets, PMS inspectors, user and community needs, network expansion and material advances) and require constant review and development.

The next two chapters examine project level systems by focussing on contemporary rehabilitation techniques and associated case studies. Design and problem solving techniques are developed and applied. The cold insitu recycling method and concrete road rehabilitation techniques have been selected to develop and demonstrate various design and evaluation tools. Despite great demand for the application of these techniques in the Western Cape, the design techniques are relatively underdeveloped and there is a need for design codes and specifications. Chapters five and six develop strategies to achieve this and evaluate the success of these methods.

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## Chapter 5: Cold insitu recycling

This chapter describes the use of cold insitu recycling (CIR) as a case study to demonstrate the implementation of systems developed for rehabilitation design and evaluation techniques. The systems described in this chapter have been developed by the author with the assistance of references 27 - 40.

The CIR technique is fast, cheap and traffic friendly and it has consequently revolutionised the road rehabilitation field. The technique was introduced to Cape Town fairly recently and its long term performance is still untested.

### 5.1 Overview

Cold insitu recycling is a technique specifically developed for the rehabilitation of existing road pavements. The process evolved during the late 1980's after extensive research and development by companies specialising in the manufacture of large milling machines. The process consists of milling the existing pavement layers to a predetermined depth, adding specific constituents such as cement or bitumen to improve the material, and then relaying the material. This is usually done with specially built machines that achieve this process in one pass.

The following constituents may be added individually or in combinations:

- water to aid compaction,
- cement, lime or other types of chemical stabilisers,
- bitumen, which may be foamed or added as an emulsion and
- imported aggregate.

Typical applications are the rehabilitation of base layers, rehabilitation of subbase layers and stabilisation of layers in new construction work.

The rehabilitation of base layers is done by milling the upper layers of the existing road and mixing them together in the process. This usually includes the surfacing layers, which can significantly enhance the grading of the mix. The material is then mixed with a stabilising agent and water, and then laid as one new layer out the back of the machine. The layer is then compacted and bladed to the correct level and a new surfacing layer is then added.

The rehabilitation of subbase layers is essentially the same as above except that one or more layers are removed first, by milling, thus enabling the CIR machine to access and recycle the deeper subbase layers. It is necessary to remove these layers first as the available technology only allows recycling and effective compaction to a maximum thickness of 300 mm.

The main advantages of the CIR process are as follows:

- Cost: it costs only a quarter of the cost of conventional methods.
- Traffic accommodation: traffic can be placed on the recycled layer almost immediately.
- Time for construction: the process decreases construction time by up to five times.
- Reuse of existing materials.
- Uniformity of mix.
- Accurate layer thickness control.

Disadvantages are that the technique cannot address subgrade problems and that it does not solve subsurface water problems.

## 5.2 Cold insitu recycling in Cape Town

The CIR technique was first used in Cape Town in 1995 when Bonteheuwel Avenue was recycled. Since then more than 45 km of road has been recycled in six different contracts (see Appendix 8). The first four roads, which have now been in use for five years and longer, are analysed in the following sections as case studies to demonstrate the rehabilitation design and evaluation techniques. These are Bonteheuwel Avenue (1995), Silverstream Road (1996), Gunners Circle (1997) and Signal Hill Road (1997). The locations of these roads are shown on the map in figure 5.1.

Plate 1 shows the CIR machinery on site. Note that expensive specialised equipment and skilled operators are essential for this form of rehabilitation.

FIGURE 5.1 LOCALITY PLAN

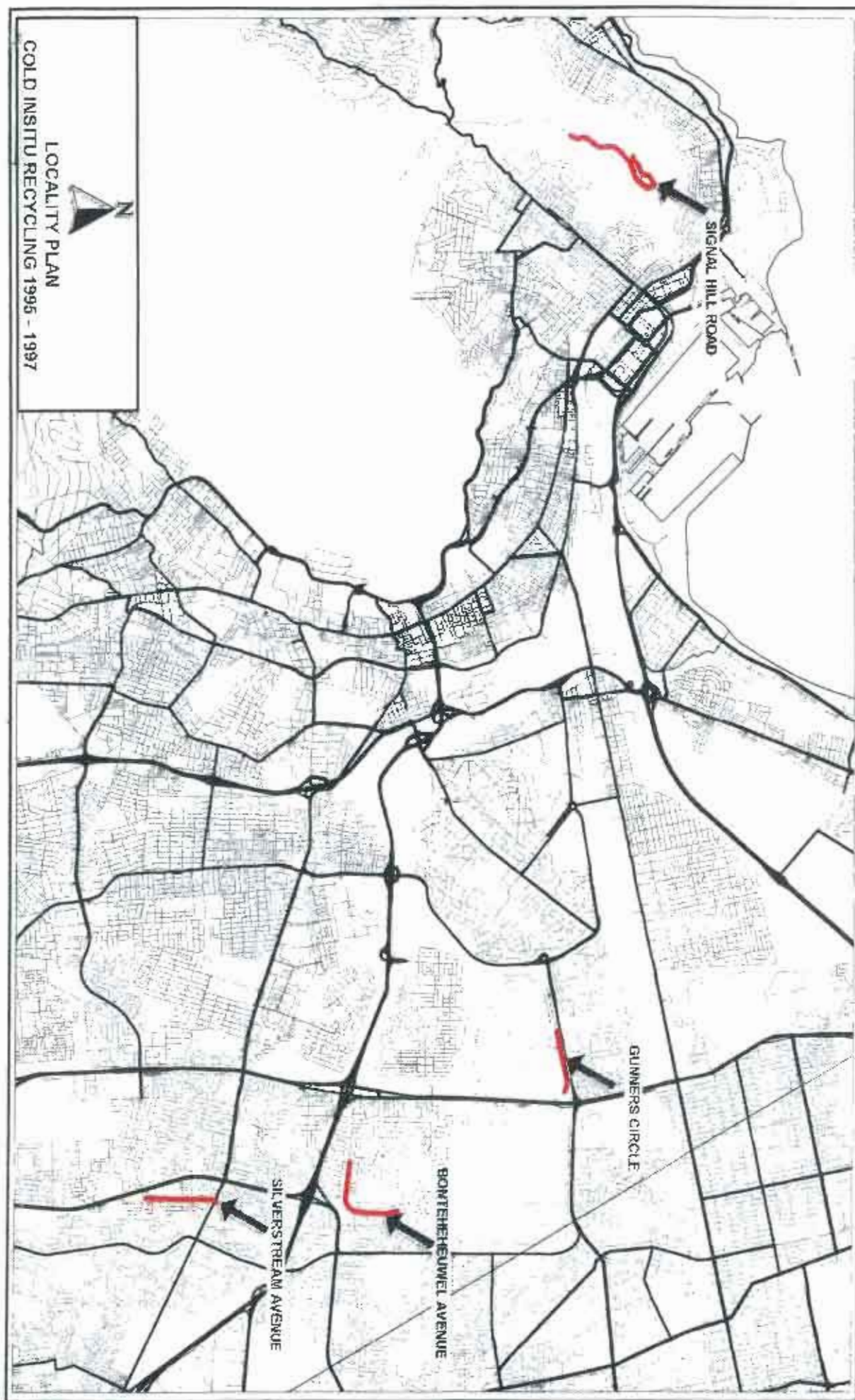




Plate 1 : CTR machine on site

### 5.3 The design process

CIR is a relatively new technique and detailed design guidelines are still being developed. International guidelines are not generally applicable because of South Africa's unique pavement structures, material types and climate. The design processes described in this chapter have been developed by the Author but are largely based on the methods developed by the South African Bitumen and Tar Association (SABITA) [39], [40] and TRH 4 [37] and TRH 12 [38]. These manuals are widely adopted throughout South Africa. However, it is acknowledged that the empirical nature of the design methods is unsatisfactory and current research being carried by the Foamed Asphalt Working Group, formed by the Road Pavements Forum, using the heavy vehicle simulator should go some way to establishing a more empirical-mechanistic design relationship for CIR structures [32].

The three steps of the design process; namely, suitability decision, structural design and mix design, are described below.

#### 5.3.1 Suitability decision

The CIR method has sometimes been used indiscriminately. A decision process to select the suitability for the CIR method is shown in figure 5.2 below:

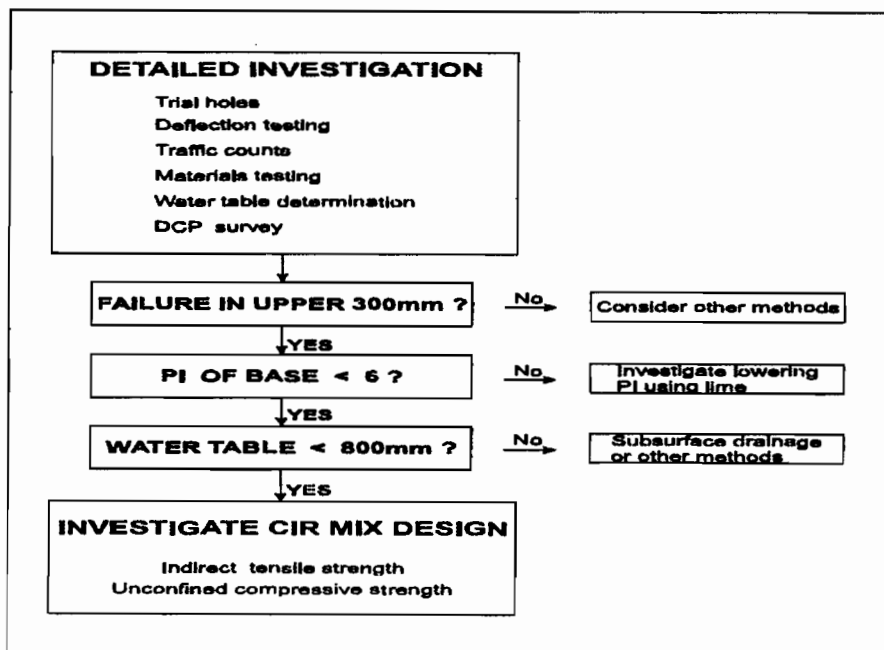


Figure 5.2: CIR suitability decision process

### 5.3.2 Structural design

The structural design can be divided into:

#### a) Traffic analysis

The cumulative E80 design traffic loading is determined using the TRH 4 [37] method. It is calculated from:

$$\text{Cumulative E 80} = G_x \cdot F_y \cdot F \cdot x \quad (5.1)$$

Where  $G_x$  = Traffic growth factor (TRH 4: table 1)

$F_y$  = Cumulative equivalent traffic (TRH 4: table 12)

$F$  = Load equivalency factor (TRH 4: table 6)

$x$  = Average daily heavy traffic

For example; in the case of Signal Hill Road, with an average daily traffic of 900 equivalent vehicle units and average daily heavy traffic ( $x$ ) of 40 units, we find the following:

- a)  $F = 2.5$ ,  $G_x = 1.03$ ,  $F_y = 9045$ , and hence
- b) the cumulative E 80 = 931635

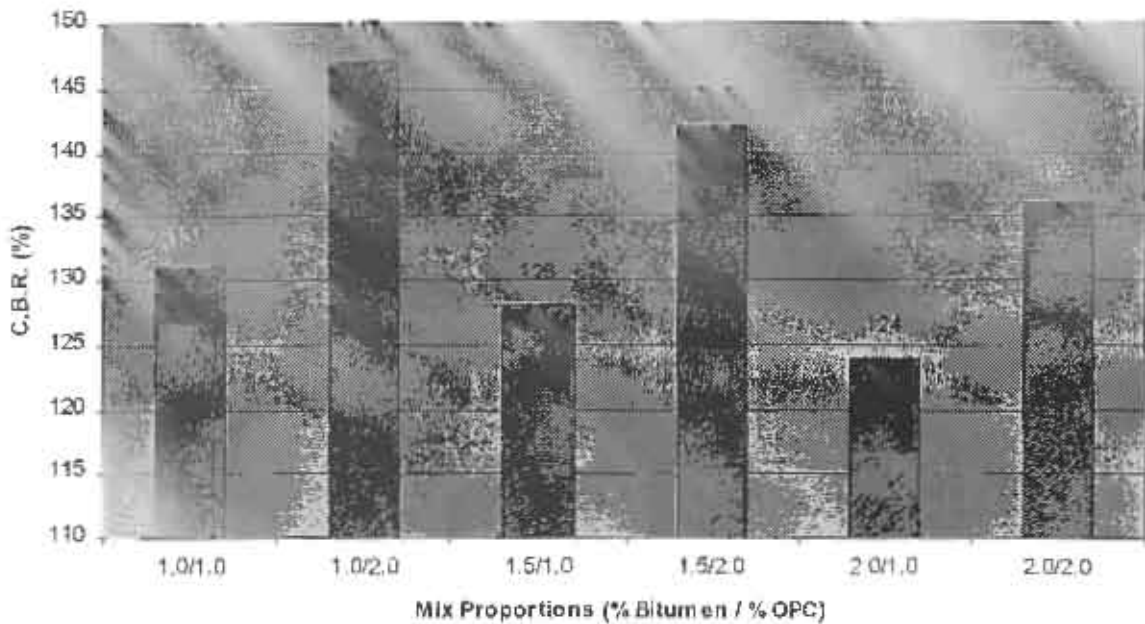
This indicates a category B road, this information can then be used to select a catalogue design [38]. The E80 load can further be used as the loading input in a mechanistic design determination.

#### b) Layer design

The South African Mechanistic Design Method (SAMDM) [33, 36] (see section 5.4.3 for explanation of the method) and the ETB Catalogue [39] can be used to determine the required pavement layers by imputing the subgrade properties and the design E80's. In the case of Signal Hill Road the SAMDM recommends an equivalent 150 mm G2 layer (see TRH 4 [37] for properties of G2 material).

### 5.3.3 Mix design

The constituent materials design to convert the existing parent material to an equivalent G2 (in the case of Signal Hill Road) is achieved by testing different emulsion/cement trial mixes in the laboratory. The mixes are then tested for CBR and UCS to determine which mix best meets the design strength criteria as determined in the layer design. An output example is shown graphically in the figure 5.3 below:



**Figure 5.3: CIR trial mixes**

As seen in the above figure, there is an increase in CBR with an increase in cement content, but a decrease with increasing emulsion content. The strength requirement must therefore be balanced with the benefits of increased emulsion content. Experience has shown that emulsion contents of above 2% result in compaction problems because of the associated high moisture content caused by the 40% water content of the emulsion mix. It is therefore best to aim at achieving the required strength at 1.5% to 2.0% emulsion content. However, in dry environments lower emulsion contents are adequate and more economical.

### 5.3.4 Case Studies

The following is a summary of the design criteria and outputs for the four case studies under investigation:

#### Case 1: Bonteheuwel Avenue

##### Background

Bonteheuwel Avenue is a residential collector road and a bus route. The road had extensive crocodile cracking and pumping.

##### Pavement structure

The pavement structure consisted of:

40 mm asphalt 190 mm ferricrete Cape Flats sand.
--

The pavement structure was deficient for the loading and this coupled with a fluctuating high water table, had caused the failure of the ferricrete base.

##### Traffic loading

The 20 year design traffic load was calculated according to TRH 4 [37] to be three million E80's

##### Design

The guidelines in SABITA's Manual 14: Gems - The design and use of granular emulsion mixes [40], were used as a basis for the CIR design. A DCP survey indicated that the lower layers were structurally adequate and that the upper 200 mm required strengthening. Laboratory tests on the base course indicated a G6 material in terms of TRH 4. The material was well graded but CBR and Atterberg limits were borderline for basecourse material. After investigation, the CIR rehabilitation technique was chosen for the following reasons:

- Basecourse required strengthening and subgrade support was adequate.
- Cost effective, about 1/3 the cost of conventional methods.
- Traffic could be accommodated at all times.
- Short construction period (about four weeks).
- Emulsion treated base would be less susceptible to damage from high water table.

Samples of combined asphalt and ferricrete were evaluated in terms of UCS, CBR and ITS. All strength criteria were met at a 1% emulsion and 1% cement content, but due to the high water table in the area it was decided to increase the emulsion content to 1.5%. A 160mm recycled layer thickness was determined by using the SAMDM.

## Case 2: Silverstream Road

### Background

Silverstream Road is a residential collector, category C road in Manenberg. The road was severely cracked and deformed.

### Pavement Structure

The pavement structure consisted of:

20 mm continuously graded asphalt wearing course 300 mm calcrete basecourse Cape Flats sand subgrade.
---

The calcrete had a plasticity index of 5, which is below the CIR selection criteria of 6. CBR values ranged from 28 - 57 which is well below the minimum basecourse requirement of 80. The calcrete was therefore a G6 type gravel of subgrade quality and had insufficient bearing capacity for the traffic loading.

### Traffic loading

In 1995 it carried an average daily heavy traffic of 30 vehicles and the 20 year design load was estimated to be 0.95 million E 80's

### Design

Cold insitu recycling was chosen as the most cost effective treatment to strengthen the poor basecourse material. Samples of combined asphalt and calcrete were evaluated in terms of UCS, CBR and ITS.

Engineering properties were evaluated at varying emulsion and cement contents. All strength criteria were met at a 2% emulsion and 2% cement content. A 110 mm layer thickness was determined using the SAMDM.

### **Case 3: Signal Hill Road**

#### **Background**

Signal Hill Road is an amenity road providing a scenic route from Kloof Nek to the end of Signal Hill. The road was identified for rehabilitation in 1996 because of severe crocodile cracking and pumping which had developed into potholes. Degree 4 deformations were covering more than 90% of the road surface.

#### **Pavement structure**

The pavement structure consisted of:

10 mm slurry seal 80 mm granite bitumen penetration (BPN) decomposed shale subgrade.
--

The granite BPN comprised a 30 mm single sized granite stone, held together with bitumen. The bitumen had completely stripped away leaving the aggregate loose in places. The subgrade conditions were acceptable but insufficient at such shallow depths.

#### **Traffic loading**

The road carries a significant amount of heavy vehicles in the form of tourist busses, up to 25 a day are recorded during summer. The cumulative E 80 design load was calculated to be 931635.

#### **Design**

A design thickness of 160 mm with 2% cement and 2% emulsion was chosen using the SABITA design method [39].

### Case 4: Gunners Circle

#### Background

Gunners Circle, Epping, is classified as a major industrial, category B Road. The road displayed category 5 crocodile cracking over more than 50% extent and most of the cracks were pumping fines.

#### Pavement structure

The pavement structure consisted of:

50 mm asphalt wearing course
70 mm bitumen penetration
200 mm ferricrete
Cape Flats sand subgrade.

#### Traffic loading

It carries approximately 4900 vehicles per direction per day of which 10% are heavy vehicles. This translates to a 20 year design load of 8.8 million E80's.

#### Design

Testing pointed to a weakness in both the BPN and ferricrete layers thus favouring the use of cold insitu recycling as a rehabilitation measure.

All strength criteria were met at a 1.6% emulsion and 2% cement content. A 160 mm layer thickness was determined using the SAMDM [36].

## 5.4 Performance analysis

A performance analysis procedure which has been developed by the Author is described in this section. Because the CIR method was only recently introduced to Cape Town, the available data is not sufficient to do a complete analysis and the purpose of this section is thus rather to demonstrate the procedure and not to produce a definitive output. The procedure is shown in the flow chart below:

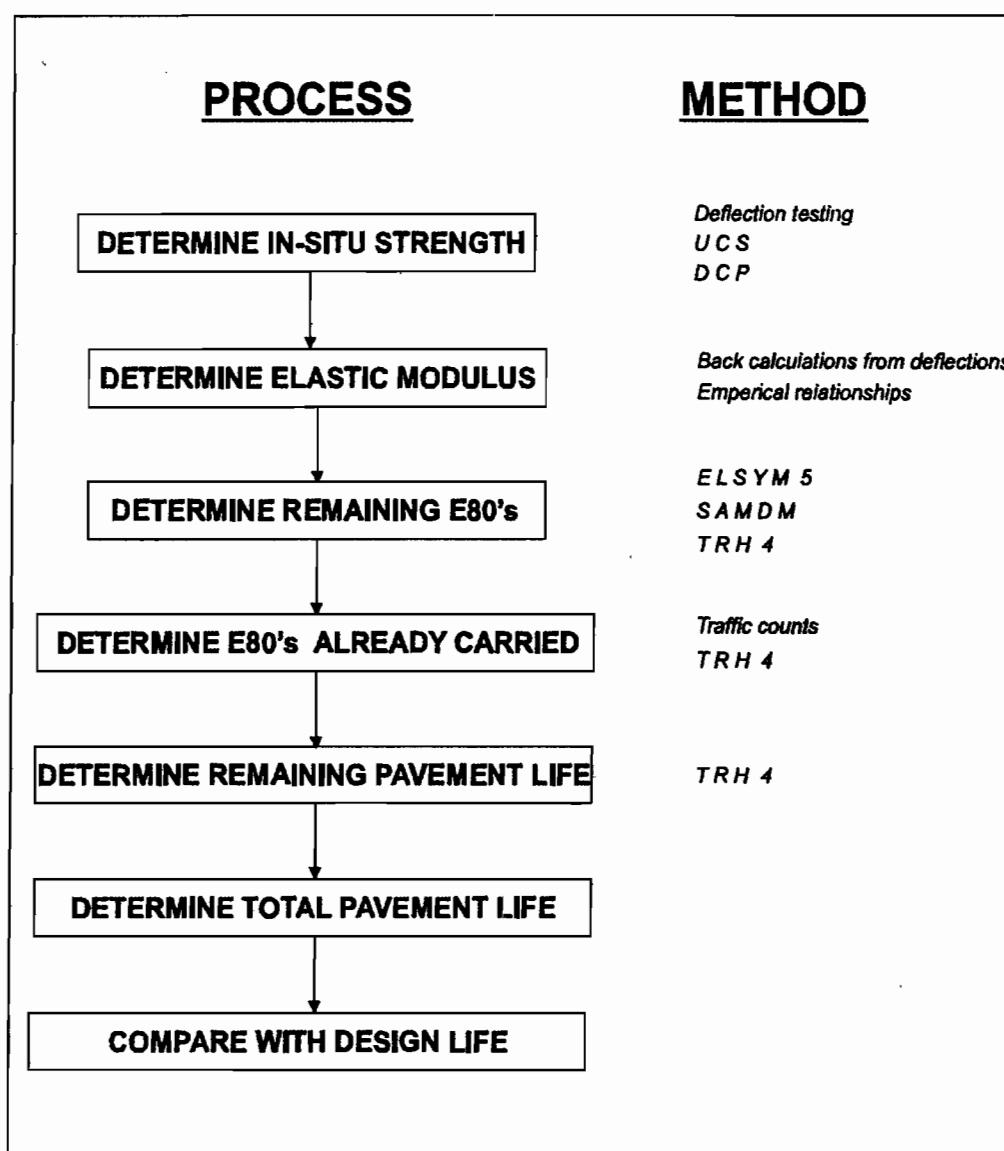


Figure 5.4: Summarised performance analysis procedure

The following test procedures have been used to evaluate the performance of the roads:

#### 5.4.1 Visual inspections

A pavement management visual inspection was done on each road in 1995, 1997, 1999 and 2000. A visual condition index for each inspection was calculated using the VCI formula described in chapter 4. The calculated values from each inspection are tabulated below in **table 5.1** and then shown in a graphical format in **figure 5.5**. Note the effect of interventions which increase the VCI to values between 86 and 93.

Road	1995	1997	1999	2000
Bontecheuwel Avenue	52	no data	no data	86
Silverstream Road	24	88	87	87
Signal Hill Road	43	40	91	81
Gunners Circle	49	40	93	88

**Table 5.1: Visual condition index**

The visual condition index gives a useful guide to the overall road condition versus time. The data shows that the CIR method can increase the VCI to an approximate value of 90. There are not enough data to extrapolate a performance curve but very little or no decrease is evident during the first four years.

#### 5.4.2 Insitu strength survey

Initially an attempt was made to recover cores from the recycled layers so that UCS and ITS's could be done directly on the materials. This, however, proved unsuccessful as it was impossible to remove the cores intact.

Insitu strengths were determined using the dynamic cone penetrometer (DCP). A list of DCP surveys that were done is shown in **Table 5.2** (see Annexure 9 for a sample survey). This information gives perspective on the frequency of available data and its relationship to the rehabilitation actions. The three year interval in testing seems to give sufficient detail to plot change in condition but more future data is required to verify this (see **Figure 5.6**, p 58).

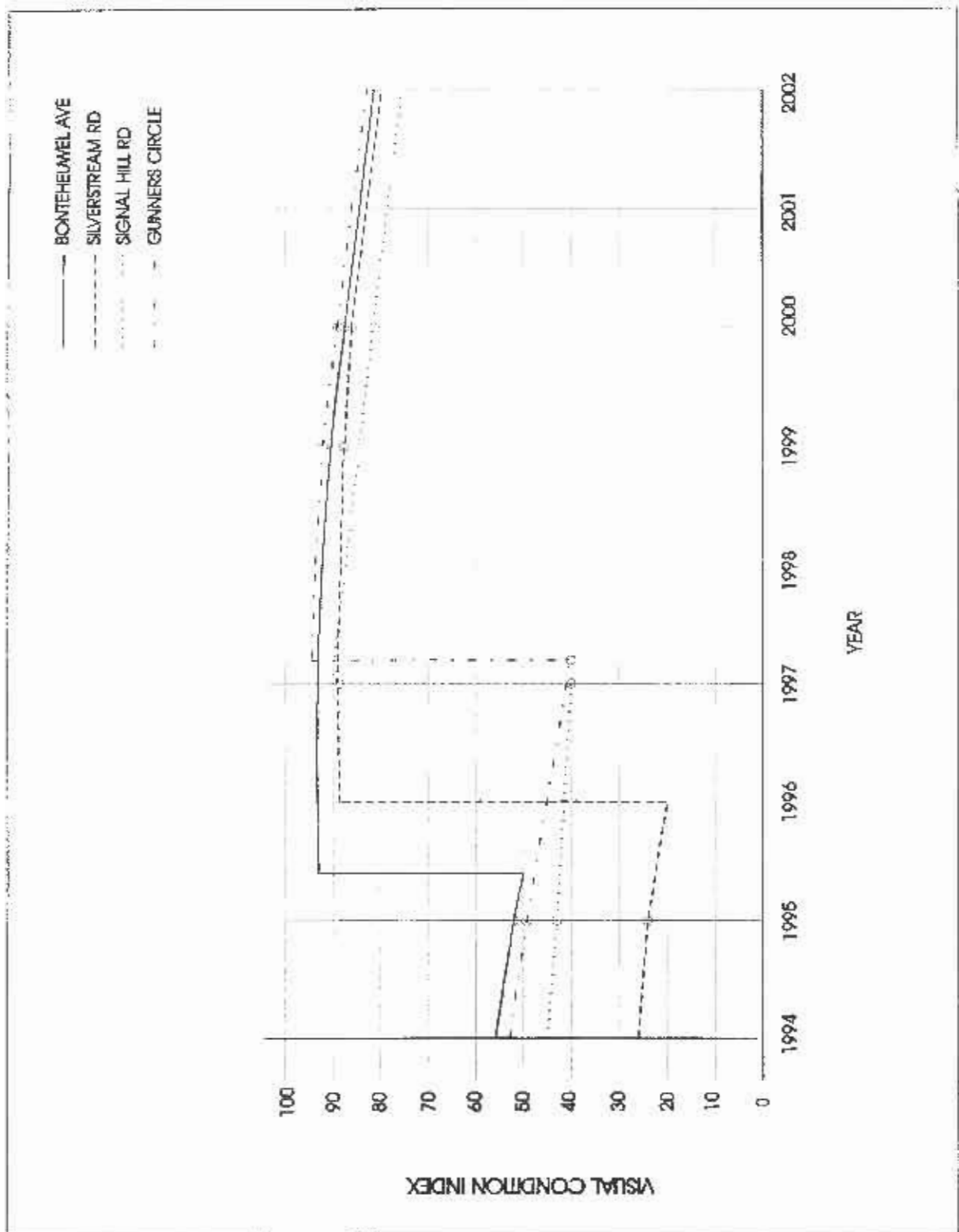


Figure 5.5: Graphical representation of visual condition index

Road	Date of survey	comment
Bonteheuwel Avenue	1993, 1995, 2000	recycled in 1995
Silverstream Road	1995, 1996, 2000	recycled in 1996
Signal Hill Road	1996, 1997, 2000	recycled in 1997
Gunners Circle	1994, 1997, 2000	recycled in 1997

**Table 5.2: DCP Survey dates**

The purpose of the DCP surveys is to obtain insitu values of CBR, UCS and E- moduli of the pavement layers and to use these values to estimate structural capacity. The structural capacity can then be used to evaluate the success of the cold insitu recycling technique. The following equations have been used to convert the DCP data: (It is noted that these relationships, equations 5.2 to 5.5, are empirical and based entirely on the South African experience. International methods are not applicable because of the unique materials and pavement structures developed in South Africa. Because the CBR, UCS & E/DCP relationships have also not been adequately researched on emulsion treated materials, all results should be treated with caution and wherever possible correlated with a mechanistic determination like deflection testing.)

UCS values have been derived from the following formula [35] and are shown in table 5.3:

If average penetration rate (DN) > 2 mm/blow:

then:

$$\text{CBR} = 410 * \text{DN}^{(-1.27)} \quad (5.2)$$

and if DN ≤ 2 mm/blow:

then:

$$\text{CBR} = (66.66 * \text{DN}^2) - (330 * \text{DN}) + 56.33 \quad (5.3)$$

UCS values are derived from the following formula [29]:

$$\text{UCS} = 15 * \text{CBR}^{0.88} \quad (5.4)$$

Table 5.3 presents calculated UCS values and the improvement in UCS is shown graphically in figure 5.6. Note the initial gain in strength over time which is probably the result of curing and densification through trafficking. It would be useful to know the properties of this gain and how it will influence early traffickability of the recycled layer before the surfacing is added. Some work on this was done on this by Jenkins et al. [29] using the MMLS Mk3 accelerated pavement tester which indicated a strength gain up to 20 000 axle repetitions.

Road	Control testing laboratory design value <sup>a</sup>	Before recycling	After recycling ( 10 - 20 days )	Current (2000)
Bonteheuwel Av	643	600	1458	2500
Silversteam Rd	1811	800	?	2500
Signal Hill Rd	1058	150	?	1500
Gummers Circle	2112	400	2200	2400

<sup>a</sup>curing: 45 hrs @ 60 °C, five days under damp saw dust

Table 5.3: Average UCS values for basecourse (kPa)

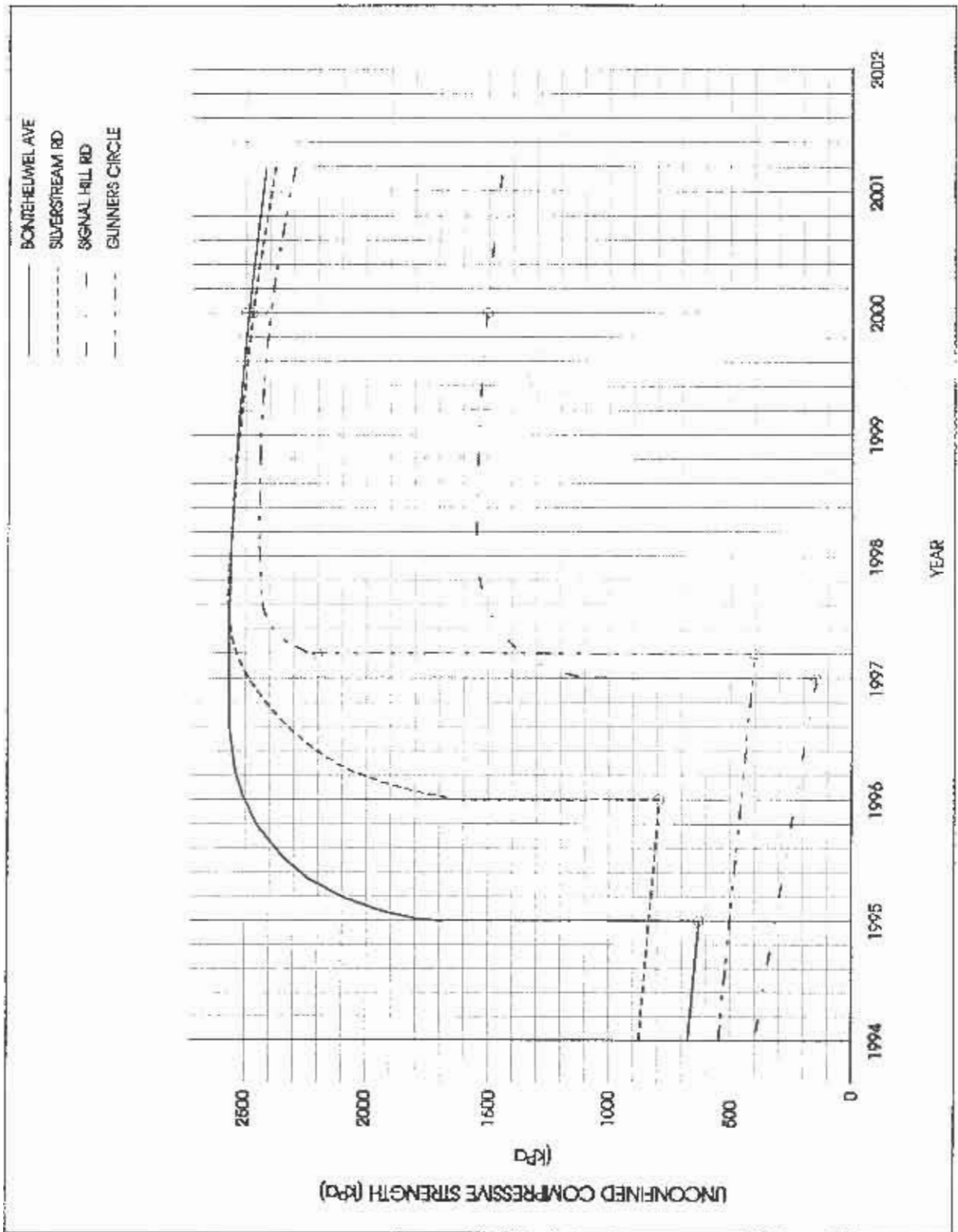


Figure 5.6: UCS values for CIR base

### 5.4.3 Structural capacity according to the South African Mechanistic Design Method

This method was introduced in the 1970's and has since been extensively tested and developed using the South African fleet of Heavy Vehicle Simulators (HVS) [33]. The method was mainly developed by the CSIR and was first published as a practical method in 1983. The method is based on the linear elasticity theory and models pavement response to a standard design load (40 kN dual wheel load at 350 mm spacing between centres and a uniform contact pressure of 520 kPa is used in this investigation, although increasing wheel loads and tyre pressures will require that this be reviewed).

The structural analysis carried out by the method involves a linear elastic, static analysis of a multi-layer system. The modulus of elasticity and cohesion of the pavement materials are used to calculate the pavement response to the loading condition. The response is expressed in terms of stresses ( $\sigma$ ) and strains ( $\epsilon$ ) at critical positions in the pavement structure. Transfer functions are then used to relate the stress-strain condition to the number of loads that can be sustained at that stress-strain level before a certain terminal condition is reached. The flow diagram below (figure 5.7) shows how the design process is implemented.

The SAMDM is the state of the art pavement design method in use in South Africa at present. It has been used to develop TRH 4: Structural design of flexible pavements for inter urban and rural roads [37] and TRH 12 : Bituminous pavement rehabilitation design [38], both of which are widely used by rehabilitation engineers throughout South Africa. In this thesis the ELSYM 5 [27] and PADS [36] computer programmes are used for the analysis.

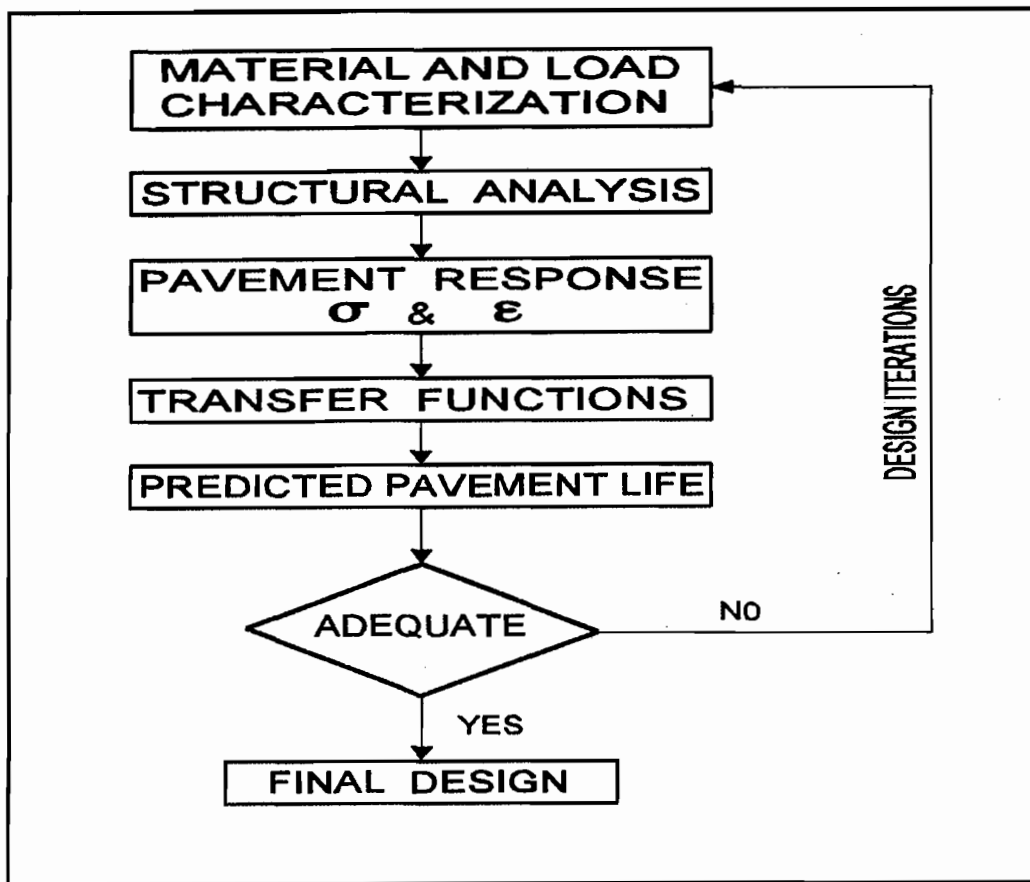


Figure 5.7: Flow diagram for a mechanistic design analysis procedure [33]

#### 5.4.4 Effective elastic moduli ( $E_{eff}$ )

In order to perform the analysis, the effective elastic modulus needs to be provided. E - moduli are estimated using the following formula [35] (unless otherwise indicated):

$$\log(E_{eff}) = 3.04758 - 1.06166(\log(DN)) \quad (5.5)$$

where,

$E_{eff}$  = Effective elastic moduli (40 kN wheel load, based on back calculation using maximum deflection)

DN = Weighted average DCP penetration rate in mm/blow

Again it must be pointed out that this formula has not been calibrated on emulsion/cement treated material. Where results have been obtained from recovered samples or from deflection testing, good correlation is indicated. However, further research is required to verify this.

E moduli before and after construction of each road are tabulated below in tables 5.4 a-d.

Before			After		
Depth (mm)	Description	$E_{eff}$ (MPa)	Depth (mm)	Description	$E_{eff}$ (MPa)
0 - 80	Asphalt CGWC	750 *	0 - 40	Asphalt CGWC	6000 *
80 - 330	Ferricrete	600	40 - 200	ETB	2500
330 - 800	Sand	95	200 - 330	Ferricrete	600
			330 - 800	Sand	95

Table 5.4a: E moduli for Bonteheuvel Avenue

Before			After		
Depth (mm)	Description	$E_{eff}$ (MPa)	Depth (mm)	Description	$E_{eff}$ (MPa)
0 - 30	Asphalt CGWC	1000 *	0 - 40	Asphalt CGWC	6000 *
30 - 330	Calcrete	350	40 - 150	ETB	2500
330 - 800	Grey sand	75	150 - 330	Calcrete	350
			330 - 800	Grey Sand	75

Table 5.4b: E moduli for Silverstream Road

Before			After		
Depth (mm)	Description	$E_{eff}$ (MPa)	Depth (mm)	Description	$E_{eff}$ (MPa)
0 - 10	Slurry	0	0 - 40	Asphalt CGWC	6000 *
10 - 40	Asphalt CGWC	750 *	40 - 200	ETB	1058
40 - 120	Granite BPN	150	200 - 800	Decomposed shale	100
120 - 800	Decomposed shale	100			

Table 5.4c: E moduli for Signal Hill Road

Before			After		
Depth (mm)	Description	$E_{eff}$ (MPa)	Depth (mm)	Description	$E_{eff}$ (MPa)
0 - 50	Asphalt CGWC	1300 *	0 - 40	Asphalt CGWC	6000 *
50 - 120	Granite BPN	400 #	40 - 200	ETB	2400
120 - 320	Ferricrete	220 #	200 - 330	Ferricrete	220 #
320 - 800	White sand	100 #	330 - 800	Sand	100 #

Table 5.4d: E moduli for Gunners Circle

The following applies to tables 5.4 a-d:

\* Values obtained from: Overview of the South African Mechanistic Pavement Design Analysis Method, Table 3, p 9. [33]

# Analysis of IDM falling weight deflectometer test results on Gunners Circle, Nov 95.

The E moduli of 2500 MPa obtained for the natural gravels correlates well with the experiments carried out with the MMLS on Vanguard Drive [29]. The quantities of fines in the natural gravels easily absorb the emulsion cement mixture and are then able to form a matrix in which the larger aggregates are cemented. The much lower values obtained for Signal Hill Road are understandable considering the poor quality (high PI and gap grading) of the decomposed shale.

#### 5.4.5 Design life

Design life has been calculated using the ELSYM 5 [27] and the PADS [36] mechanistic design programmes.

The following input parameters were used:

Load force :	40 kN dual wheel load at 350 mm spacing
Contact pressure :	520 kPa
Cohesion of ETB:	350 kPa

Design life predictions are shown in **table 5.5** (See **Appendix 10** for sample output):

Road	Design E80's for 20 year life <sup>*</sup>	E80's already carried	Remaining E80's <sup>#</sup>	Remaining life <sup>†</sup>
Bonteheuwel Av	$3.00 \times 10^6$	$0.75 \times 10^6$	$2.0 \times 10^6$	11 years
Silverstream Rd	$0.95 \times 10^6$	$0.10 \times 10^6$	$2.0 \times 10^6$	> 20 years
Signal Hill Road	$1.30 \times 10^6$	$0.20 \times 10^6$	$1.0 \times 10^6$	20 years
Gunners Circle	$8.80 \times 10^6$	$1.50 \times 10^6$	$3.5 \times 10^6$	9 years

\* Based on initial traffic counts. See **Appendix 11** for a calculation example [37].

# From ELSYM 5 [27] and PADS [36] predictions

† Back calculated using TRH4 [37]

**Table 5.5: Design life predictions**

Silverstream Road and Signal Hill Road, which carry relatively low traffic loads, are predicted to easily fulfill the 20 year design life specification. Bonteheuwel Avenue had already carried six years of traffic at the time of this survey, giving a total life of 17 years which is not significantly less than the design life. Similarly, the total life for Gunners Circle is 12 years, which is significantly less than the 20 year design life. Gunners Circle carries the highest traffic loading of the four roads and the analysis therefore suggests a possible under design at high traffic loads.

## 5.5 Conclusions

CIR is a cost effective and traffic friendly construction method. The evaluation system on the four case studies show that after six years of trafficking there is no significant visual deterioration to any of the four recycled roads. More data are required to develop a deterioration curve.

In situ strength determinations and the resultant structural analysis show that three of the four roads are performing according to the initial design criteria. Gunners Circle has a predicted design life of 12 years which is significantly below the 20 year design life and this suggests possible under design at high traffic loading.

Insitu testing of ferricrete and calcrete, recycled with cement and emulsion, shows that an effective elastic modulus of 2500 MPa is achievable. Results show that there is a significant strength gain for a period after recycling. More testing is required to determine the period when this gain occurs and to quantify the gain.

There are many variables that cause uncertainty in the use of the SAMDM for structural analysis of cold insitu recycled roads and comparison with actual performance of the roads after they have failed is required to increase confidence. The cohesion value for different recycled materials needs to be further researched as the SAMDM is very sensitive to this value.

After six years of performance, all indicators point to the successful performance of the cold insitu recycling of calcrete, crushed hornfels and ferricrete bases. It is recommended that further evaluations be done after 10 and 15 years to obtain an actual deterioration curve.

Whilst CIR is an appropriate treatment for flexible asphalt pavements, concrete roads present a different challenge and approaches to concrete road rehabilitation are explored in chapter 6.

## **Chapter 6: Concrete road rehabilitation [41 - 44]**

In the 1950's and 60's over 50 km of residential concrete strip roads were constructed on the Cape Flats. The concrete slabs are 120 to 180 mm thick, mostly unreinforced and placed directly on the compacted sand subgrade. Most of these roads require rehabilitation and because of the huge expense to remove the concrete and completely rebuild the road, various rehabilitation techniques have been developed. These techniques have achieved varying degrees of success. Because of the enormity of this problem and the associated cost implications, there is an urgent need to evaluate the options and recommend cost effective solutions.

### **6.1 Concrete road failures and defects**

The following problems are present on Cape Town's strip concrete roads:

**1) Loss of subgrade support:** this can be attributed to the following factors (see plates 2-5):

- Settlement of the supporting layers. Since most of these roads were constructed directly on the insitu material, significant settlement must have occurred.
- Heaving clays. Clay lenses are present in varying degrees on the Cape Flats.
- High water table. Calcrete lenses cause a perched water table which saturates the subgrade and can reduce bearing capacity by 80%. This exacerbates the pumping effect described below.
- Warping of the slab.
- Erosion of the support layers by pumping. Very small initial vertical movements (rocking) of the slab relative to the subgrade can create substantial hydraulic forces in the resulting void. Water entering the pavement, often at the joints, is sucked in and out of the void as the slab rocks, causing erosion of the material.

**2) Concrete degradation:** Many of the concrete slabs have extensively ravelled leaving the aggregate standing proud by upto 30 mm. This results in an extremely uncomfortable driving surface which can damage tyres. This may be caused by segregation of the concrete during construction, weak concrete mixes and a loss of surface strength resulting from micro-cracking caused by alkali aggregate reaction with the hornfels aggregate (see plates 4-7).

**3) Disintegration of joints:** Most of the joints do not appear to have been sealed or else the sealants have completely disintegrated. Consequently the joints, which are up to 50 mm wide are open resulting in ingress of water, very poor riding surface and possible damage to tyres (see plate 4).

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4) **Lack of joints:** Some sections of road have insufficient spacing of joints resulting in weaving transverse contraction cracks to have opened up at about six metre spacings. Some of these cracks are up to 15 mm wide and pose a danger to vehicles.

**Photographs of the different failure types are shown in plates 2 to 9:**

**Plate 2** shows a concrete slab with broken corners that have been patched with asphalt. This is caused by rocking of the slab which causes supporting material to be pumped out of the unsealed joint (Hardepeer Street, Bonteheuwel, 2000).

**Plate 3** shows joint disintegration and adjacent cracking due to erosion of supporting material. Note how the cracked piece has subsided due to lack of support (Hardepeer Street, Bonteheuwel, 2000).

**Plate 4** shows joint disintegration and ravelling resulting in exposed aggregate. Note the comparison with the slabs on the far side of the road which were most likely added on at a later date (Hardepeer Street, Bonteheuwel, 2000).

**Plate 5** shows slab faulting and exposed aggregate. The hornfels aggregate is angular and sharp and could damage vehicle tyres (Hardepeer Street, Bonteheuwel, 2000).

**Plate 6** shows micro cracking caused by alkali aggregate reaction (NY 11, Guguletu, 2001).

**Plate 7** shows severe ravelling leaving sharp exposed hornfels aggregate (NY 11, Guguletu, 2001).

**Plate 8** shows how slab movement causes reflective cracking in the asphalt overlay. Note how the asphalt has bulged on either side of the crack, this is caused by sand filling the crack and restricting movement (Vlamboom Street, Bonteheuwel, 2000).

**Plate 9** shows the full road with a combination of defects (Firethorn Street, Bonteheuwel, 2000).

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## Concrete road failures and defects



Loss of support resulting in cracking  
of slab corners  
PLATE 2



Lack of support, raveling and joint disintegration.  
PLATE 3



Joint disintegration and raveling resulting  
in exposed aggregate  
PLATE 4



Slab faulting and exposed aggregate.  
PLATE 5



Alkali aggregate reaction  
PLATE 6



Ravelling resulting in exposed aggregate.  
PLATE 7



Movement at joint causing cracking  
in asphalt overlay.  
PLATE 8



Various defects -- exposed aggregate, loss of  
support, joint disintegration  
PLATE 9

## 6.2 Treatment options

Amongst others, the following options have been considered and their advantages and disadvantages are listed.

### 6.2.1 Complete reconstruction

This is the most radical option and entails complete removal of the concrete and construction of new pavement structure. It has the following advantages:

- Complete new road with excellent driving surface and geometrics.
- Long design life.
- Solution of drainage and level problems.

while disadvantages can be summarised as follows:

- Very expensive.
- Road has to be closed to traffic during construction.
- Long construction period.
- Possibly vulnerable to sub surface water.

### 6.2.2 Asphalt overlay

This technique entails repairing defects in the concrete pavement and then overlaying with asphalt. The asphalt layer could be anything from 10 mm to 50 mm in thickness. Kerb and channel and road widening can be added at the same time. The success of the technique is heavily dependent on the type of overlay and on the joint treatment.

The following types of overlay have been used:

- i. 5 - 10 mm Ralumac slurry
- ii. 40 mm continuously graded asphalt hotmix
- iii. 40 mm open graded asphalt hot mix
- iv. 20 - 40 mm rubber modified asphalt hotmix.

Before the overlay is placed the concrete joints are sealed with a modified binder (rubber or polymer modified) and then bridged with either a glass grid or a geofabric (see plates 10 & 12). Another option is to saw cut a 5 to 10 mm slot above the joint after the asphalt has been laid and then seal the slot with a modified bitumen sealant (see plates 11 & 15).

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The advantages of this technique are summarised as:

- Relatively cheap.
- Quick.
- Minimal disruption to traffic.
- Opportunity to improve grades and stormwater runoff.
- Initial excellent driving surface.
- Existing concrete is retained forming an excellent basecourse.

while disadvantages include:

- Success very dependent on crack treatment and type of overlay.
- Joints will cause reflective cracking through the asphalt.
- Reflective cracking will require regular maintenance.
- Relatively short lifespan of 5 to 10 years.

### 6.2.3 Concrete Recycling

This technique entails using a mobile concrete crushing plant to recycle the concrete and relay it as a basecourse. It is essentially a full reconstruction but has the advantage of reusing the existing materials. The concrete is removed using a hydraulic excavator or other suitable plant and then fed into the mobile crushing plant (see plate 14). The plant removes any steel reinforcing and then crushes the concrete into a 37.5 mm continuously graded basecourse. The material is then laid and compacted to 98% modAASHTO and then covered with a 40 mm CG asphalt wearing course. It is usually necessary to slush sand into the base because of a lack of fines in the crushed material.

Some advantages are:

- Complete new road with excellent driving surface and geometrics.
- Long design life.
- Solution of drainage and level problems.
- Cheaper than complete reconstruction.
- Makes use of existing materials - environmentally friendly.

while disadvantages include:

- Relatively expensive.
  - Road has to be closed to traffic during construction.
  - Possibly vulnerable to sub surface water.
  - Lack of fines make base difficult to compact.
-

#### 6.2.4 Crack and seat method

This method entails cracking the concrete slabs using a 700 kg weight with a guillotine type blade or flat impact head which is dropped from a height of 1.2 m. The idea is to break the concrete into pieces of not greater than 600 x 600 mm (this is calculated using a co-efficient of expansion of  $11 \times 10^{-6}$  and a 40°C temperature range). Seating of the resulting pieces is then carried out using 25 ton pneumatic roller. A levelling course and asphalt wearing course are then added. A geofabric could be placed over the joints or over the entire surface before these layers are added.

The advantages of this technique are:

- Minimal disruption to traffic.
- Short construction time.
- Opportunity to improve levels and drainage.
- Uses existing materials - environmentally friendly.

while disadvantages include:

- Unknown design life.
- Water entering asphalt layer will penetrate through base and could cause pumping of subgrade.
- Additional expense.

**Photographs of the different treatments are shown in plates 10 to 15 on the following page.**

**Plate 10** shows a joint sealed with a rubber modified bitumen. Stone (9 mm) has been added to the bitumen to increase the stability of the mixture (NY 11, Guguletu, 2001).

**Plate 11** shows a sealed saw cut joint. Note how the sealant has been stripped out in places. (Swartysterhout Street, Bonteheuwel, 1998)

**Plate 12** shows a geofabric bandage over a joint which is applied to limit reflective cracking in the asphalt overlay (Firethorn Street, Bonteheuwel, 1996).

**Plate 13** shows a rubber bitumen asphalt overlay. Note how the sealant in the longitudinal crack, on the right of the picture, is bleeding through the overlay (Firethorn Street, Bonteheuwel, 1998).

**Plate 14** shows a concrete crushing machine. The crushed concrete product can be seen just to the right of the machine.

**Plate 15** shows an asphalt overlay with saw cut joints.

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## Treatment types



Crack sealing  
PLATE 10



Saw cut joint.  
PLATE 11



Geofabric bandage over crack.  
PLATE 12



Rubber bitumen asphalt overlay.  
PLATE 13



Concrete crusher.  
PLATE 14



Saw cut joints.  
PLATE 15

### 6.3 Performance comparisons

In order to quantify the success of the various concrete road rehabilitation options a performance analysis of selected roads has been carried out. All the roads are about 5 years old. The roads are shown in table 6.1.

No.	Road	Area	Rehab type	Crack treatment	Surfacing type	Year	Approx. unit rate (2000 rates) R/m <sup>2</sup>
1	Firethorn Street (D 0 - 160) Geelhout to Hulisbos	Bonteheuwel	Asphalt overlay	Bitumen sealant and geofabric bandage	Rubber bitumen asphalt	1996	200
2	Firethorn Street (D 160) - end	Bonteheuwel	Asphalt overlay	As above but no geofabric	Rubber bitumen asphalt	1996	190
3	Gras Street - Firethorn to Geelhout	Bonteheuwel	Asphalt overlay	None	Rubber bitumen asphalt	1995	150
4	Swarlysterhott Street	Bonteheuwel	Asphalt overlay/sawcut	Bitumen sealant / saw cut after overlay	Open graded asphalt	1996	230
5	Sherwood Walk	Hanover Park	Recycled	N/A	Continuously graded hotmix	1996	300
6	Amandel Road	Bonteheuwel	Crack and seat	Geofabric	Rubber bitumen asphalt	2000	?

Table 6.1: Concrete road rehabilitation case studies

The roads were inspected in April 2001 and scored according to the following degree and extent ratings for reflective cracks above concrete joints:

Description	Degree
No cracks present	1
Fine hairline cracks	2
Open cracks < 2 mm wide	3
Cracks 2 to 6 mm with some spalling and bulging. Bumps felt in vehicle from cracks or depressions above cracks.	4
Cracks > 6 mm with spalling and bulging. Distinctly bumpy ride.	5

Table 6.2: Degree rating for reflective cracking

Description	Degree
< 10 % of road length affected	1
10 - 20 %	2
20 - 40 %	3
40 - 70 %	4
> 70 %	5

Table 6.3: Extent rating of reflective cracking.

Table 6.4 presents the scoring for each road.

Road No	Name	Degree	Extent	Degree x Extent
1	Firethorn Street	1	1	1
2	Firethorn Street	4	1	4
3	Gras Street	3	5	15
4	Swartysterhout Street	3	2	6
5	Sherwood Walk	1	1	1
6	Amandel Road	1	1	1

Table 6.2: Road inspection scores after rehabilitation

The low score for Gras Street is a result of reflective cracking at the concrete joints and this shows the importance of crack sealing before placing the overlay. The degree 3 cracking on Swartysterhout Street is a result of ineffectual sealing of the saw cut joints (see plate 11). Degree 4 cracking on road 2 compared to the absence of cracking on road 1, shows that there is some advantage in placing a geofabric bandage.

### 6.3 Conclusions and recommendations

There are numerous methods available for the rehabilitation of concrete roads. The concrete roads on the Cape Flats are constructed in areas that have high water tables and the concrete slabs form ideal bases for rehabilitation measures. After comparing the different rehabilitation methods the following conclusions can be made.

1. The recycled concrete base has performed the best but is also the most expensive rehabilitation option. This method is closer to a full reconstruction and cannot be directly compared with the other methods.
  2. The rubber bitumen overlay on sealed joints has performed satisfactorily after six years and is economically viable and is therefore at present the most desirable treatment.
  3. The saw cut method shows promise but further research is required in methods of sealing the saw cut. If the saw cuts can be effectively sealed, this method is likely to have a longer design life than the straight overlay.
  4. The crack and seat method shows promise but it is too early to evaluate its performance.
  5. A follow up study needs to be done in three to five years time. Operational costs can then be evaluated and life cycle cost comparisons can be computed.
-

## **Chapter 7: Conclusions and Recommendations**

The reconstruction and rehabilitation needs in a city environment can be effectively managed by adopting a systematic approach. This thesis has explored the different components of such a system and these have been divided into data and information requirements and systems requirements. The components of the requirements are summarised below.

### **Data and information requirements**

The historical perspective gives information on the different techniques and types of materials that were originally used to build the roads. All these roads will require reconstruction at some stage in the future and it is essential to know how they were constructed.

The geological perspective is needed to establish the performance of subgrade and pavement materials which are influenced both by their origin and underlying geology. The geology also determines the available construction materials and their properties

### **Systems requirements**

Various systems have been developed to structure the road reconstruction process and these range from road selection (by the use of pavement management systems) to road prioritisation and design techniques.

Case studies have been used to implement design and analysis procedures and thereby develop a model for determining the success of different reconstruction options.

Conclusions for the case studies are summarised below.

1. The use of insitu testing has shown that the cold insitu recycling technique is structurally effective six years after construction. Computer models suggest that a 20 year design life can be achieved. Follow up studies need to be done after 10 and 15 years to verify these findings.
2. Numerous techniques are available to rehabilitate concrete roads but studies indicate that the rubber bitumen overlays on treated joints and the saw cut method are the preferred treatments. Further studies are required at five year intervals to develop life cycle deterioration curves.

By following the approach developed in this thesis, the engineer can effectively manage the rehabilitation requirements of a big city by optimising needs with limited funding and ensuring the implementation of successful, long term rehabilitation designs solutions.

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# APPENDIX 1

**List of tenders for reconstruction project in 1905 [11]**

NAME.	Material.	Amount.		
		£	s.	d.
S. B. Mills ...	Saldanha Bay Granite ...	162,966	13	4
Standard Asphalte Co. ...	Asphalte Blocks, 2 inches thick ...	114,708	6	8
Globe Asphalting Co. ...	Asphalte Powder, 2 inches thick ...	112,966	13	4
G. S. Firth ...	Hardwood ...	107,583	6	8
Geo. Pallett ...	Hardwood ...	104,866	13	4
Neuchatel Asphalte Co. ...	Creosoted Deal, coated ...	100,520	16	8
G. S. Firth ...	Red Deal ...	99,583	6	8
Sundberg & Dyer ...	Jarrah ...	99,322	2	2
Murray & Stewart ...	Jarrah ...	98,920	16	8
B.S.A. Asphalte Co. ...	Non-Slippery Sanitary Block ...	98,020	16	8
Murray & Stewart ...	Colonial Granite ...	91,254	3	4
Murray & Stewart ...	Blackbutt, Tallowwood, Turpentine ...	90,920	16	8
Donnelly & McCann ...	No. 1 Jarrah ...	90,379	3	4
Murray & Stewart ...	Blue Gum, Stringy Bark ...	90,254	3	4
Neuchatel Asphalte Co. ...	Val de Travers Asphalte Powder, 2 inches thick ...	89,354	3	4
Murray & Stewart ...	Swedish Granite ...	88,920	16	8
Geo. Pallett ...	Creosoted Deal ...	87,866	13	4
C. Ivor Puxty & Co. ...	Jarrah ...	86,533	6	8
R. T. Stephenson ...	Blackbutt ...	85,241	13	4
R. T. Stephenson ...	Tallowwood ...	85,241	13	4
R. T. Stephenson ...	Brush Fox ...	85,241	13	4
R. T. Stephenson ...	Red Mahogany ...	85,241	13	4
R. T. Stephenson ...	Stringy Bark ...	85,241	13	4
R. T. Stephenson ...	Blue Gum ...	85,241	13	4
E. Nuttall & Co. ...	Hastings Sanitary Blocks, 3 inches thick ...	85,200	0	0
R. T. Stephenson ...	Jarrah ...	84,241	13	4
Geo. Pallett ...	Uncreosoted Red Deal ...	83,866	13	4
Donnelly & McCann ...	N.S.W. Hardwoods ...	83,712	10	0
Murray & Stewart ...	Creosoted Deal ...	83,254	3	4
Murray & Stewart ...	Val de Travers Asphalte, 7 inches thick ...	83,004	3	4
R. T. Stephenson... ...	Creosoted Red Deal ...	81,241	13	4
Jas. Holland & Co. ...	Holland's Granite Blocks, 3 inches thick ...	80,833	6	8
Donnelly & McCann ...	Creosoted Deal ...	79,045	16	8
Table Mountain Asphalte, per R. R. Hunter ...	Table Mountain Asphalte Blocks, 2½ inches thick ...	77,300	0	0
P. Phillips Halliwell ...	N.S.W. Hardwood ...	76,483	6	8
C. Ivor Puxty & Co. ...	Sicilian Asphalte, 2 inches thick ...	72,533	6	8
Jenkins & Co. ...	Do. do. ...	72,533	6	8
B.S.A. Asphalte Co. ...	Table Mountain Asphalte Blocks, 2½ inches thick ...	66,520	16	8

## **APPENDIX 2**

**Pavement survey, 1923 [11]**

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MAIN ROADS RECONSTRUCTION—(Annexure to Section 1, Table II).

No.	NAME OF ROAD.	Length to be Reconstructed. Lineal Yards.	Width to be Reconstructed. Lineal Yards.	Area to be Reconstructed Square Yards.	Existing Surface. W.B.—Waterbound Mac. T.—Tar Present Mac.	Particulars of Foundation.	F.—Requires New Foundation	Estimated Cost of Recon- struction per Square Yard.	Estimated Cost of Recon- struction.	Estimated Annual Main- tenance per Square Yard after Reconstruction.	Estimated Annual Main- tenance after Reconstruction.	Interest and Sinking Fund at 6% on Cost of Recon- struction.	Total Estimated Annual Charges after Reconstruc- tion.	Present Annual Cost of Repairs from 1910—1921 Records.	Present Annual Cost per Square Yard in Present.	Traffic in Tons per hour per yard width.	Traffic Class.	Colour on Plan.
1	REGENT ROAD.—Main Road to Queen's Road ..	875	4.3	3,794	W.B.	None	F	23/6	£ 4,458	d. 6d.	£ 95	£ 208	£ 363	£ 206	13	10.2	B	Blue
2	QUEEN'S ROAD.—Regent Road to Victoria Drive	111	8.0	889	T.	..	F	16/-	701	5d.	21	47	68	41	10	8.2	B	..
3	MAIN ROAD, SEA POINT.—Three Anchor Bay to Regent Road	1,000	6.5	10,400	W.B.	..	F	28/-	14,560	8d.	347	871	1,221	642	14½	19.2	A	Red
4	MAIN ROAD, GREEN POINT.—Boundary Street to Three Anchor Bay (Mountain Side) ..	1,987	4.1	8,058	..	..	F	23/6	9,468	5d.	168	568	736	330	9½	12.7	B	Blue
5	SOMERSET ROAD.—Waterkant Street to Ebenezer Road ..	803	9.5	7,656	..	..	F	21/-	9,187	7d.	223	552	775	351	11	18.1	A	Red
6	SOMERSET ROAD.—Ebenezer Road to Boundary Street (Seaside) ..	180	11.0	1,980	T.	9in. Hhd. core.	F	13/6	1,337	3d.	25	80	105	30	3	7.0	C	Yellow
7	SOMERSET ROAD.—Ebenezer Road to Boundary Street (Mountain Side) ..	—	6.3	{ 197 930	T. W.B.	9in. Hhd. None	F	16/-	902	4d.	19	54	73	31	6½	11.1	B	Blue
8	WATERKANT STREET.—Irth Street to Somerset Road ..	125	7.8	975	W.B.	..	F	28/-	1,365	15d.	61	82	143	141	34½	20.0	A	Red
9	WATERKANT STREET.—Long Street to Bree Street	165	11.1	1,881	..	..	F	23/6	2,210	5d.	39	133	172	25	3½	13.5	B	Blue
10	BUITENGRACHT STREET.—Waterkant Street to Strand Street ..	83	19.0	1,577	..	..	F	16/-	1,262	6d.	39	75	114	120	18½	10.8	B	..
11	STRAND STREET.—Long Street to Bree Street ..	270	10.0	2,700	..	..	F	13/6	1,823	4d.	45	109	154	97	8½	8.0	C	Yellow
12	STRAND STREET.—Bree Street to Buitengracht Street ..	110	22.0	2,420	..	..	F	16/-	1,936	4d.	40	116	156	66	6½	10.0	B	Blue
13	ST. GEORGE'S STREET.—Dock Road to Wale Street ..	523	11.5	6,000	T.	..	F	24/-	7,200	6d.	150	432	582	195	7½	12.7	A B	Red Blue
14	BUITENKANT STREET.—Castle Street to Darling Street ..	140	20.5	2,877	W.B.	..	F	36/-	5,179	6d.	72	311	383	179	15	19.9	A	Red
15	BUITENKANT STREET.—Darling Street to Roeland Street ..	413	16.2	7,171	..	..	F	20/-	7,171	6d.	170	431	616	383	11½	13.7	A	..
16	LONGMARKET STREET.—Hanover Street to Cor- poration Street ..	509	6.0	3,054	..	..	F	28/-	4,276	6d.	76	257	333	80	6½	11.7	A	..
17	DAKING STREET.—Huitenkant Street to Sir Lowry Road (chiefly mountain side) ..	280	13.3	3,725	..	..	F	37/-	6,892	8d.	124	411	538	123	21	28.8	A	..

MAIN ROADS RECONSTRUCTION—(Annexure to Section 1, Table II).

No.	NAME OF ROAD.	Length to be Reconstructed. Lineal Yards.	Width to be Reconstructed. Lineal Yards.	Area to be Reconstructed. Square Yards.	Existing Surface. W.B.—Waterbound Mac. T.—Tar Drained Mac.	Particulars of Foundation.	F.—Requires New Foundation	Estimated Cost of Reconstruction per Square Yard.	Estimated Cost of Reconstruction.	Estimated Annual Maintenance per Square Yard after Reconstruction.	Estimated Annual Maintenance after Reconstruction.	Interest and Sinking Fund at 6% on Cost of Reconstruction.	Total Estimated Annual Charges after Reconstruction.	Present Annual Cost of Repairs from 1910—1921 Records.	Present Annual Cost per Square Yard in Present.	Traffic in Tons per hour per yard width.	Traffic Class.	Colour on Plan.
18	SIR LOWRY ROAD.—Darling Street to Victoria Road	1,567	16.2	23,787	..	..		37/-	44,000	8d.	703	2,611	3,434	2,265	23	29.4	A	..
19	VICTORIA ROAD.—Church Street to Carriage Drive	1,986	18.5	36,825	T.	Bin. Hd core		20/-	36,825	7d.	1,074	2,209	3,283	2,102	13½	14.7	A	..
20	VICTORIA ROAD.—Barron Street to Church Street	569	10.2	5,820	W.B.	None	F	30/-	8,730	12d.	291	824	815	601	24½	20.6	A	..
21	VICTORIA ROAD.—Carriage Drive to Station Road, Observatory	5	10.3	1,939	..	..	F	30/-	2,908	12d.	97	174	271	109	24½	20.5	A	..
22	MAIN ROAD (Peninsula).—Victoria Road to Groote Schuur Avenue	3,212	7.8	25,091	..	..	F	34/-	42,055	20d.	2,091	2,559	4,650	4,113	30½	10.8	A	..
23	MAIN ROAD (Peninsula).—Groote Schuur Avenue to Stanhope Road	2,426	5.8	14,071	..	..	F	34/-	23,921	16d.	938	1,435	2,373	1,805	30½	31.3	A	..
24	MAIN ROAD (Peninsula).—Stanhope Road to Mains Avenue	1,650	6.2	6,913	T.	..	F	34/-	17,423	11d.	470	1,045	1,515	953	22½	22.7	A	..
TOTALS—Table II.		19,802 Lin. Yds.		181,172 Sq. Yds.					256,494		7,177	15,399	22,867	15,361				

MAIN ROADS RECONSTRUCTION—(Annexure to Section 2, Table III).

25	STUCKERIS STREET.—Sir Lowry Road to Newmarket Street	67	18.4	1,231	W.B.	None	F	28/-	1,721	10d.	51	103	151	119	23	19.0	A	Red
26	NEWMARKET STREET.—Stuckeris Street to Albert Road	979	13.2	12,889	W.B.	..	F	20/-	18,015	10d.	537	1,083	1,620	677	12½	25.8	A	..
27	ALBERT ROAD.—Newmarket Street to Salt River Road	2,332	14.3	33,264	W.B.	..	F	20/-	33,264	9d.	1,217	1,996	3,243	2,244	16	19.0	A	..
28	SALT RIVER ROAD.—Main Road to Albert Road	538	7.8	4,214	W.B.	..	F	24/-	5,057	9d.	158	303	461	350	20½	17.7	A	..
29	LOWER MAIN ROAD.—Station Road, Observatory to Main Road	580	7.0	4,582	T.	..	F	28/-	6,415	12d.	229	385	614	423	22½	20.5	A	..
30	LOWER MAIN ROAD.—Albert Road to Station Road, Observatory	1,074	8.3	7,472	T. W.B.	..		20/-	8,872	7d.	259	532	791	691	10½	16.3	A	..
31	MAIN ROAD (Inland).—Albert Road to Across Main Railway Line	559	12.3	6,861	T.	..		20/-	6,861	10d.	286	412	698	692	24½	17.9	A	..
32	MAIN ROAD (Inland).—(Through Maitland) to Main Railway to Municipal Boundary	4,321	12.7	51,011	W.B.	..		20/-	51,011	7d.	1,802	3,295	4,897	3,379	14½	14.0	A	..
33	WALE STREET.—Adderley Street to Long Street	260	6.3	1,617	T.	..	F	28/-	2,306	7d.	48	138	186	113	18½	13.2	A	..
34	KLOOF STREET.—Long Street to end Tram Line	1,507	5.7	8,604	T.	..	F	20/-	8,604	6d.	215	510	731	575	16½	10.5	B	Blue
35	HATFIELD STREET.—Vrede Street to Orange Street	543	7.0	3,801	T.	..		16/-	3,041	6d.	95	183	278	144	9	14.5	B	..
TOTALS—Table III.		12,763 Lin. Yds.		140,879 Sq. Yds.					140,103		4,727	8,946	13,673	9,416				





# APPENDIX 3

**Material outputs, 1923 [11]**

MATERIALS USED ON ROADS AND FOOTWAYS.

Description.	Sea Point C. yds.	Capo Town C. yds.	Woodstock C. yds.	Maitland C. yds.	Mowbray C. yds.	Claremont C. yds.	Kalk Bay C. yds.	Total. C. yds.
Macadam .. ..	3,047	8,562	3,460	3,725	4,404	6,458	1,423	31,088
Gravel .. ..	2,255	818	121	7,813	4,319	5,095	519	20,940
Binding .. ..	—	1,972	374	—	1,252	—	152	3,750
Shingle .. ..	12	1,608	506	60	—	—	—	2,174
Tar Toppings .. ..	—	640	—	—	—	—	16	656
Tar Macadam .. ..	—	1,980	27	—	—	—	—	36
Seconds .. ..	—	53	—	—	—	—	—	53
Sand .. ..	—	—	—	—	—	—	—	—
Blue Rock .. ..	—	226	—	—	—	—	—	226
Cobbles .. ..	—	165	—	—	—	—	—	165
Grit .. ..	—	1,958	601	1,951	75	735	830	6,860
Hardcore .. ..	—	13	17	30	—	—	—	60
Boulder Stone .. ..	—	50	—	1,422	—	—	75	1,547
Sandstone .. ..	—	275	—	—	—	—	—	275
Random Stone .. ..	—	—	—	—	—	—	131	131
<b>Total .. ..</b>	<b>5,314</b>	<b>18,320</b>	<b>5,115</b>	<b>15,001</b>	<b>10,750</b>	<b>12,288</b>	<b>3,182</b>	<b>69,970</b>
	<b>Casks.</b>	<b>Casks.</b>	<b>Casks.</b>	<b>Casks.</b>	<b>Casks.</b>	<b>Casks.</b>	<b>Casks.</b>	<b>Casks.</b>
Tar .. ..	—	788	735	—	323	46	46	1,938
Traverite .. ..	—	60	—	—	—	138	—	138





# APPENDIX 4

Road reconstruction project, 1929 [11]

PROGRESS REPORT.—MAIN ROADS RECONSTRUCTION, JANUARY TO DECEMBER, 1928.  
ACTUAL EXPENDITURE.

N <sup>o</sup> . in Reconstruction Scheme.	Road Reconstructed.	Point to Point.	Area of Roadway Sq. Yds.	Nature of Surfacing.	Nature of Foundation.	Contract No.	Contract Costs.	Depreciational Costs.	Total Costs.
							£ s. d.	£ s. d.	£ s. d.
18	Sir Lowry Rd. .. ..	Darling - Barton St. .. ..	—	—	—	2	—	101 3 10	101 3 10
19	Victoria Rd. .. ..	Church St.—Scott Rd. .. ..	—	—	—	2	—	43 8 3	43 8 3
22	Main Rd., Mowbray .. ..	Penzance Rd.—Mowbray Elm. .. ..	—	—	—	2	299 3 0	47 4 11	346 7 11
24	Victoria Rd. .. ..	Barron—Church St. .. ..	—	—	—	2	4 7 10	—	4 7 10
		Total Contract No. 2 .. ..	—	—	—		297 10 10	191 17 0	488 7 10
22	Main Rd., Randelbosch .. ..	Mowbray Elm.—Grool Schuur Av. .. ..	—	—	—	4	—	7 6 9	7 6 9
23	Main Rd., Clarendon .. ..	Grool Schuur Av.—Proton Rd. .. ..	—	—	—	4	315 12 7	—	315 12 7
27	Albert Rd. .. ..	Barron—Essex St. .. ..	—	—	—	4	173 4 0	—	173 4 0
		Total Contract No. 4 .. ..	—	—	—		518 16 7	7 6 9	526 3 4
3	Main Rd., Sea Point .. ..	Chengriff Rd.—Round Church .. ..	9,722	3" Stone-filled S.A.	6" Concrete	5	10,535 16 4	6,492 11 7	17,028 7 11
54	Hanover St. .. ..	Darling - Windsor St. .. ..	—	—	—	5	698 9 5	—	698 9 5
19	Durham Rd. .. ..	Overhead Bridge—Cape End. Rd. .. ..	—	—	—	5	305 5 9	—	305 5 9
—	Maitland Rd. .. ..	Ranpenberg Rd.—Station .. ..	—	—	—	5	1,116 12 1	2,526 15 7	3,642 17 8
—	Kloof Rd., Sea Point .. ..	St. John's Rd.—Round Church .. ..	300	3" Stone-filled S.A.	6" Concrete	5	678 8 10	713 0 9	1,391 9 7
—	Slurpmarkt St. .. ..	St. George's—Hess St. .. ..	—	—	—	5	98 0 6	—	98 0 6
53	Parliament St. .. ..	Darling - Spin St. .. ..	—	—	—	5	100 10 4	—	100 10 4
		Total Contract No. 5 .. ..	10,022	—	—		13,882 18 3	7,225 12 4	21,107 20 7
								2,526 15 7	23,634 16 4
								4,008 16 9	27,643 17 3
—	Roosendal Av. .. ..	Chichester Rd.—Wynberg Rd. .. ..	—	—	—	6	215 3 10	—	215 3 10
		Total Contract No. 6 .. ..	—	—	—		215 3 10	—	215 3 10

PROGRESS REPORT.—MAIN ROADS RECONSTRUCTION, JANUARY TO DECEMBER, 1928.

ACTUAL EXPENDITURE—(continued).

No. in Reconstruction Scheme.	Road Reconstructed.	Point to Point.	Area of Roadway Sq. Yds.	Nature of Surfacing.	Nature of Foundation.	Contract No.	Contract Costs.	Departmental Costs.	Total Costs.
							£ s. d.	£ s. d.	£ s. d.
32	Main Rd., Maitland	Main Line—Municipal Bdy.	41,572	3" Stone-filled S.A.	Macadam	7	18,675 9 1	2,220 0 8	27,904 0 9
34	Main Rd., to Maitland	Albert Rd.—Main Line Bdy.	3,523	3" Stone-filled S.A.	Macadam	7	1,580 19 1	1,752 1 9	3,333 0 10
35	Koeburg Rd.	Main Rd.—Municipal Bdy.	3,901	2" Asphaltic Concrete	Macadam	7	5,609 5 5	2,530 17 1	8,200 2 6
			9,213	2 1/2" Stone-filled S.A.					
37	Maitland Rd.	Camp Gnd.—Raapeberg Rd.	7,068	2" Asphaltic Concrete	Macadam	7	2,152 4 1	2,452 18 8	4,645 2 9
			1,307	1 1/2" Asphaltic Concrete					
	Klipfontein Rd.	Dorhan Rd.—Flats Railway	15,349	2 1/2" Stone-filled S.A.	Macadam	7	6,408 3 4	6,568 8 3	13,000 11 7
			3,063	2 1/2" Asphaltic Concrete					
38	Klipfontein Rd. Ext.	Flats Railway—Municipal Bdy.	23,579	2" Asphaltic Concrete	Macadam	7	4,581 15 1	7,103 10 8	11,748 11 9
			2,580	2 1/2" Asphaltic Concrete					
	Hout St.	St. George's—Long St.	619	3" Stone-filled S.A.	6" Concrete	7	908 10 8	334 3 9	1,243 3 5
	Church St.	St. George's—Long St.	788	3" Stone-filled S.A.	6" Concrete	7	852 10 0	141 19 0	1,014 15 6
33	Wale St.	Alderley—Long St.	691	3" Stone-filled S.A.	6" Concrete	7	440 17 7	2,186 13 8	2,627 10 19
	Park Rd.	Camp Ground—Mihner Rd.	5,587	2" Asphaltic Concrete	Macadam	7	1,031 18 9	45 12 5	1,677 9 2
47	Hatfield Rd.	Main Rd.—Kensworth Rd.	8,005	2" Asphaltic Concrete	Macadam	7	2,866 5 5	2,073 11 4	6,529 19 9
		Total Contract No. 7	126,266				45,951 11 6	35,139 0 4	80,990 17 10
57	Brownlow Rd.	Mihner—Burnside Rd.	—	Penetration	Macadam	—	—	403 18 1	403 18 1
	Laurelwood Rd. Ext.	Kromboom Bidge—Achtal Acre	6,140	—	—	—	—	5,218 0 7	5,218 0 7
	Strand St. Islands	—	—	—	—	—	—	523 17 0	523 17 0
	Flushing Machines	—	—	—	—	—	—	3,784 11 9	3,784 11 9
		Total Similies	6,140					9,910 19 5	9,910 19 5
Loan 32 A	Maitland Rd.	Raapeberg Rd.—Station	—	—	—	—	—	2,991 2 4	2,991 2 4
Loan 33 A on 2770	Klipfontein Rd.	Storm Water Drainage	—	—	—	—	—	323 14 5	323 14 5
Loan 34 A on 849	Park Rd., Rillach.	Storm Water Drainage	—	—	—	—	—	966 12 0	966 12 0
Loan 35 A on 222	Salt River Bridge	Reconstruction	—	—	—	—	—	97 0 9	97 0 9
		Total other Loans	—					4,378 9 6	4,378 9 6



MAIN ROADS.—RECONSTRUCTION OF CARRIAGEWAYS IN 1928.

Road Reconstructed.	Point to Point.	Length L. Yds.	Area of Carriage- way. S. Yds.	Nature of Surfacing.	Nature of Foundation.	Previous Nature of Surfacing.
Main Rd., Sea Point ..	Glenariff Rd.—Round Church ..	1,632	15,026	3" Stone-filled S.A. ..	6" Concrete	Waterbound Tarred.
Kloof Rd., Sea Point ..	St. John's Rd.—Round Church ..	75	300	3" Stone-filled S.A. ..	6" Concrete	Waterbound Tarred.
Main Rd. to Maitland ..	Albert Rd.—Main Line Bridge ..	248	3,523	4" Stone-filled S.A. ..	Macadam	Waterbound Tarred.
Main Road, Maitland ..	Main Line Bridge—West Bdy ..	2,510	38,001	3" Stone-filled S.A. ..	Macadam	Waterbound Tarred.
Koeberg Rd. ..	Main Rd.—vicinity of Public School ..	1,152	9,243	2 1/2" Stone-filled S.A. ..	Macadam	Waterbound Tarred.
Maitland Rd., Mowbray ..	Raapenberg Rd.—Station ..	135	1,207	2" Stone-filled S.A. ..	Macadam	Waterbound Tarred.
Maitland Rd., Mowbray ..	Camp Ground Rd.—Raapenberg Rd. ..	910	7,008	2" Asphaltic Concrete ..	Macadam	Waterbound Tarred.
			1,307	1 1/2" Asphaltic Concrete ..		
Klipfontein Rd. ..	Durban Rd.—Flats Railway ..	3,524	13,349	2 1/2" Stone-filled S.A. ..	Macadam	Waterbound, part Tarred.
			3,063	2 1/2" Asphaltic Concrete ..		
			23,570	2" Asphaltic Concrete ..	Macadam	Ironstone Gravel
Klipfontein Rd. Extension	Flats Railway—Municipal Bdy ..	3,000	2,550	2 1/2" Asphaltic Concrete ..		
Barfield Rd. ..	Main Rd.—Kenilworth Rd. ..	1,385	10,005	2" Asphaltic Concrete ..	Macadam	Waterbound Tarred.
Lansdowne Rd. Extension	Kromboom Bridge—Aldel Arcus ..	877	6,140	Penetration ..	Macadam	Ironstone Gravel.
Hout Street ..	St. George's St.—Long St. ..	136	840	3" Stone-filled S.A. ..	6" Concrete	Waterbound Tarred.
Church St. ..	St. George's St.—Long St. ..	139	788	3" Stone-filled S.A. ..	6" Concrete	Waterbound Tarred.
Wale St. ..	Adlerley St.—Long St. ..	260	801	3" Stone-filled S.A. ..	6" Concrete	Waterbound Tarred.
	Totals, 1928 ..	15,919	135,973			

62.04 miles

Mileage per annum of Roads Reconstructed.

1923 ..	1.11 miles.
1924 ..	1.13 ..
1925 ..	1.51 ..
1926 ..	5.91 ..
1927 ..	5.03 ..
1928 ..	9.04 ..

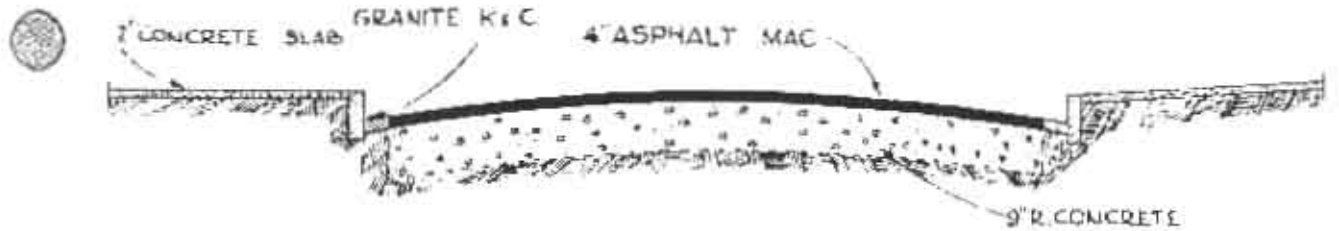
Total mileage of Roads Reconstructed, 1923-1928 .. 27.63 ..



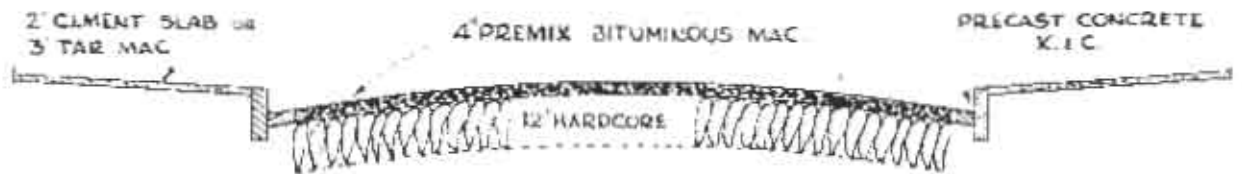
## APPENDIX 5

Road pavements, 1936 [4]

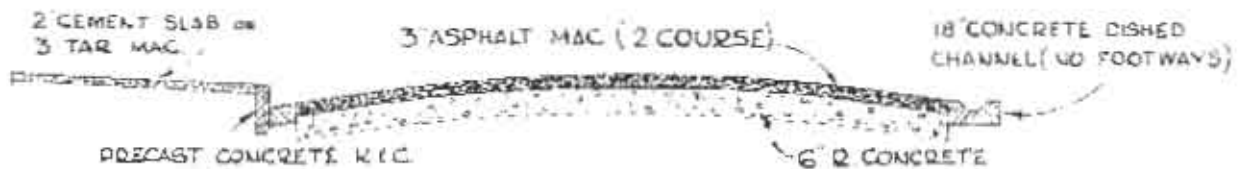
# PROFILES ADOPTED BY LATE MR. T. P. FRANCIS



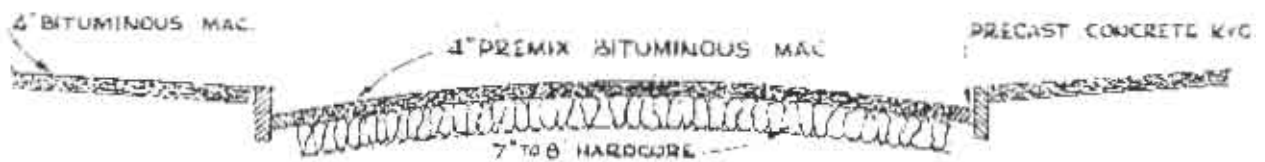
**TYPE N<sup>o</sup> 1  
MAIN ROAD**



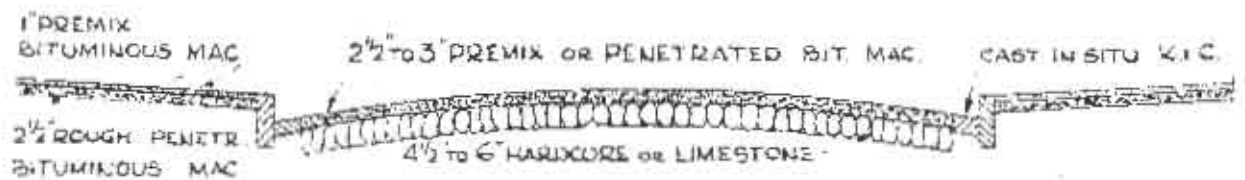
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ARTERIAL ROADS**



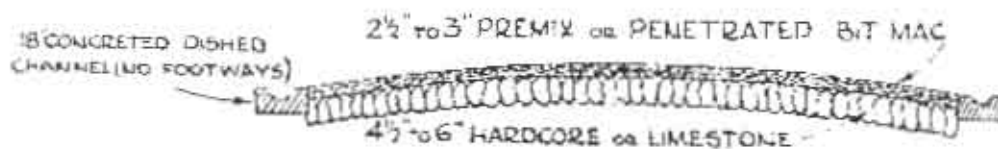
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ARTERIAL ROADS**



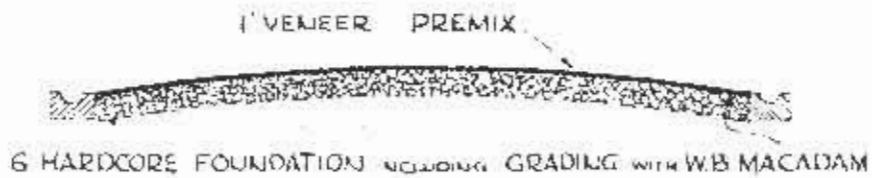
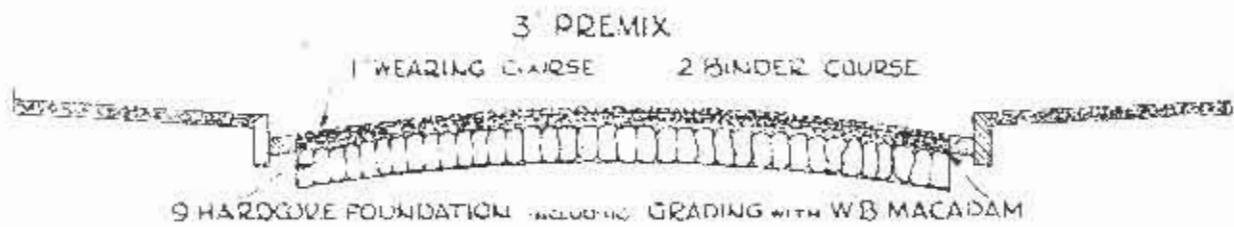
**TYPE N<sup>o</sup> 3  
LINK ROADS**



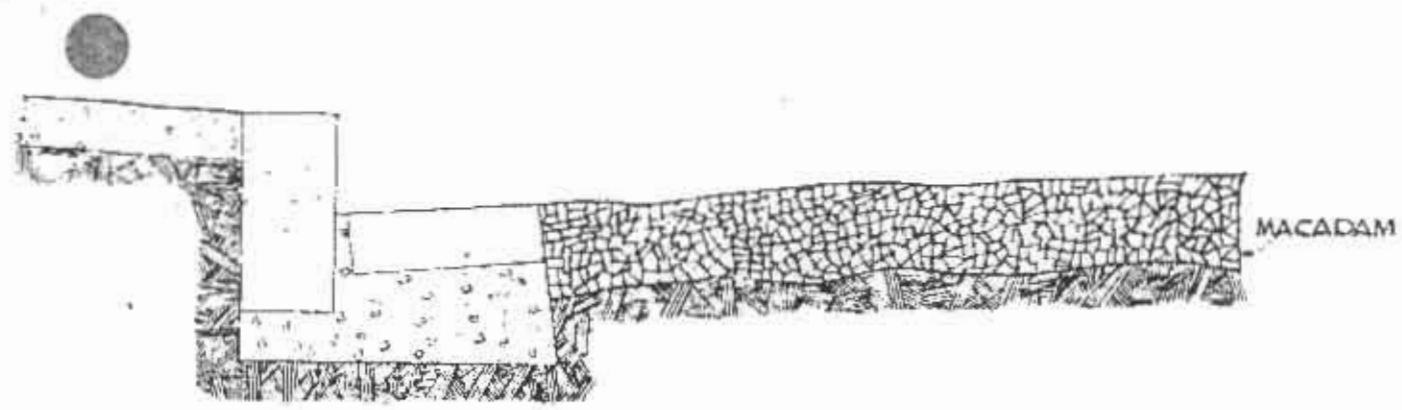
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DEVELOPMENT ROADS**



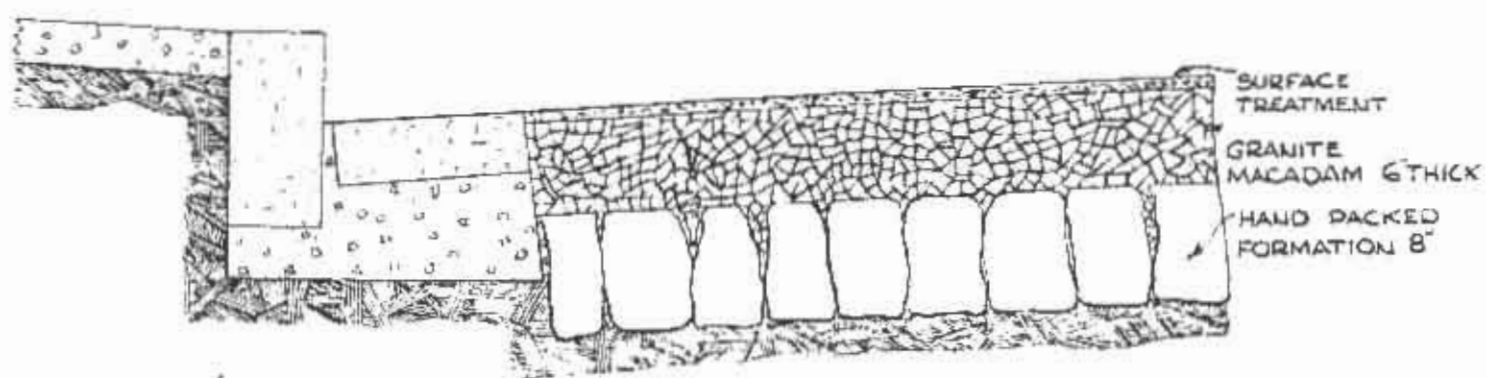
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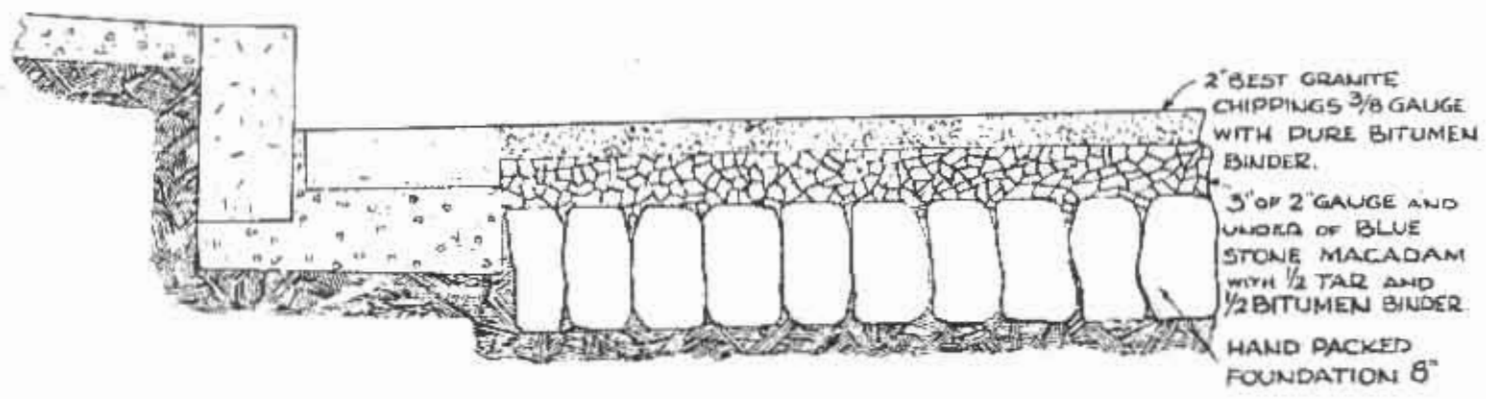
PROFILES ADOPTED BY LATE DE. LLOYD-DAVIES 1915



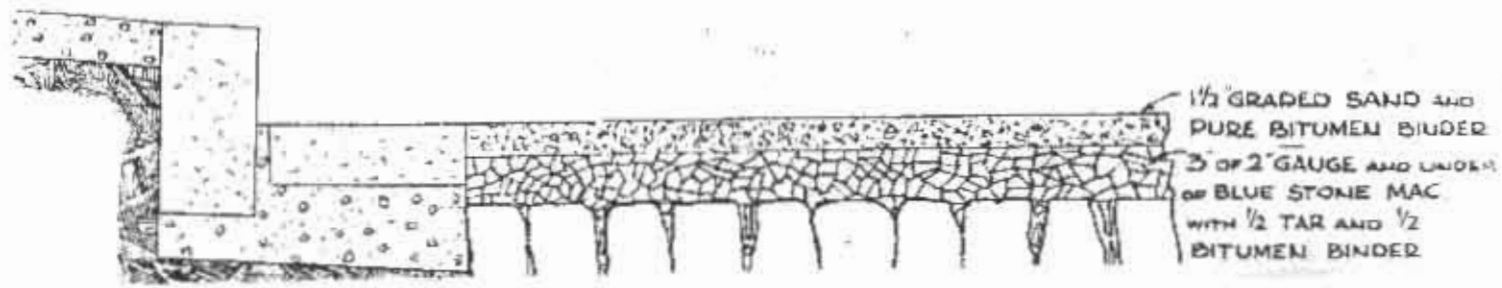
EXISTING MACADAM ROAD — NO FOUNDATION  
TO BE ABANDONED



STANDARD TYPE SECONDARY ROAD  
COST PER SQUARE YARD - 8/-

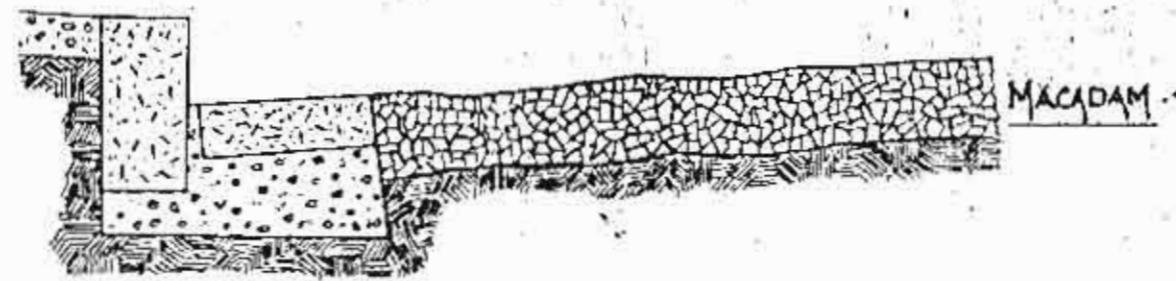


FIRST CLASS MAIN MOTOR ROADS STANDARD TYPE-A  
COST PER SQUARE YARD 11/-

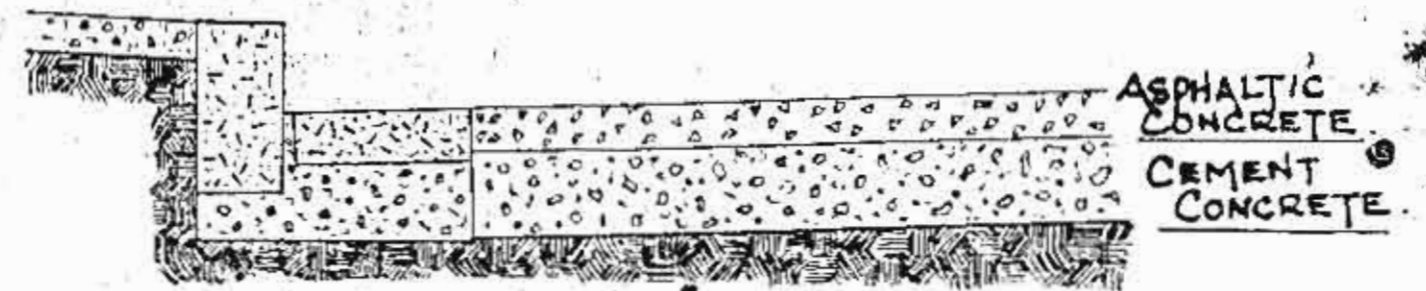


# TYPICAL SECTIONS OF ASPHALT ROADS.

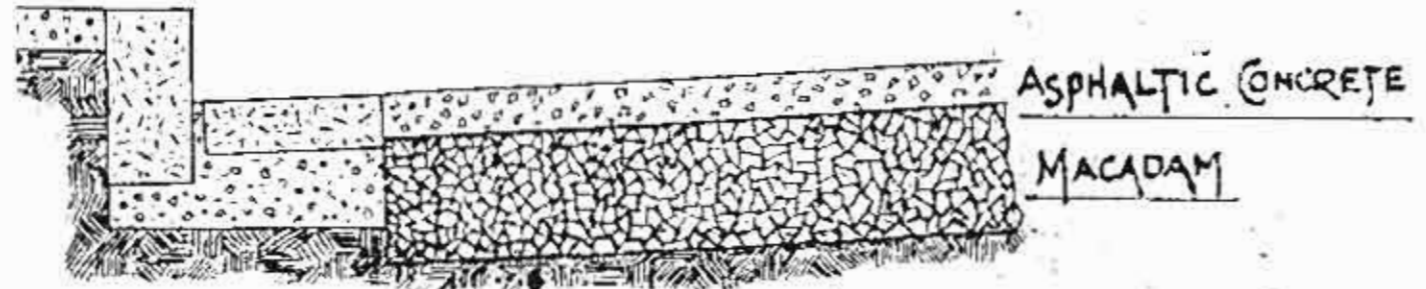
SCALE: 1" TO A FOOT.



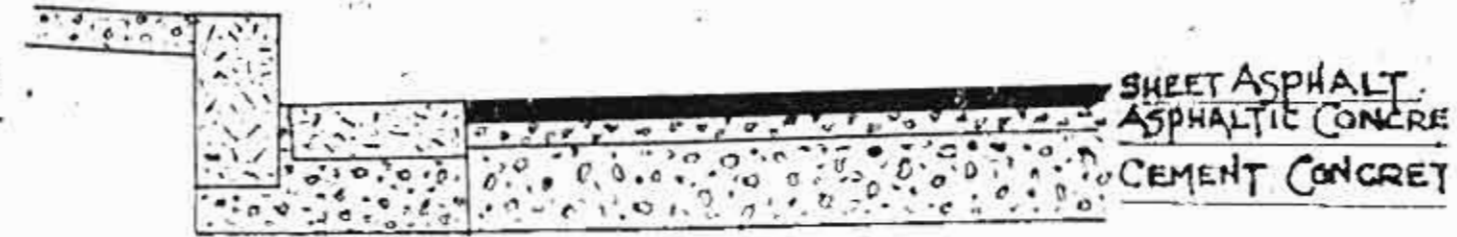
1. EXISTING MACADAM ROAD - NO FOUNDATION



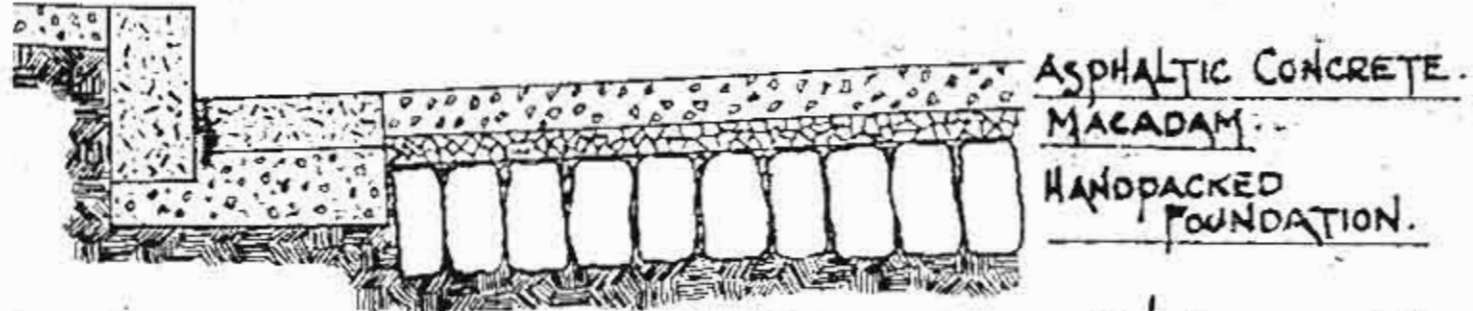
No. 4. 3" ASPHALTIC CONCRETE ON 6" CEMENT CONCRETE.



2. 3" ASPHALTIC CONCRETE ON 9" ORDINARY MACADAM AS EXISTING.



No. 5. 1/2" SHEET ASPHALT } ON 6" CEMENT CONCRETE.  
2" ASPHALTIC CONCRETE



3. 3" ASPHALTIC CONCRETE ON 2" MACADAM ON 8" HANDPACKED FOUNDATION.

M. 42  
24

# APPENDIX 6

Road cost comparisons, 1937 [3]

COMPARATIVE COSTS.

APPENDIX C.

Bitumen Grouted and Premix Road Surfaces.

Type of Surface.	Duty.	Prime Cost.		Saving in Capital. per Mile.	Interest and Redemption - Loan 20 years at 3½% per annum per mile.	Maintenance Costs per Annum per Mile.	Total Cost per Annum		Savings per Annum Interest and Maintenance.	
		Per Sq.Yd.	Per Mile x 24'				Per Mile	Per Sq.Yd.	Per Mile.	Per Sq. Yd.
"Penetrated" 3½"	Heavy	7/3d. (Foundations 2/9d) (Surface 4/6d)	£5,125		£370	£59	£429	7.3d		
"Premix" 2 Coat	"	6/11d (Foundations 2/9d) (Surface 4/2d)	£4,900		£352	Nil	£352	6d		
				£225					£77	1.3d
"Penetrated" 2½"	Light	5/9d (Foundations 2/- ) (Surface 3/9d)	£4,068		£292	£59	£353	6d		
"Premix" 1½" Veneer	Light	5/- (Foundations 2/- ) (Surface 3/6d)	£3,520		£253	Nil	£253	4.3d		
				£548					£100	1.7d

NOTE:

On the above figures two courses are open for comparison:-

- (a) Limit Annual Capital Expenditure.
- (b) " " Mileage Constructed.

(a) Limiting Capital Expenditure to £60,000 per annum:

13 miles of "Penetrated" roads could be built while Interest, Redemption and Maintenance would be £5,082.  
or 14.6 " "Premix" " " " " " " " " " " " £4,416.

or (b) Limiting Annual Road Programme to 13 Miles:

13 miles "Penetrated" would cost £60,000 with Interest, etc. @ £5,082.  
or 13 " "Premix" " " £55,000 " " " " " £3,932.

In short 12.3% more road construction can be done for the same capital expenditure in addition to 13.1% reduction in the Interest, Redemption and Maintenance Costs.



Appendix 7

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# APPENDIX 7

**PMS inspection sheet**







# APPENDIX 8

List of roads recycled in Cape Town 1995 - 2000



## Roads cold insitu recycled in Cape Town Municipality 1995 - 2000

Road	Location	length (m) Area (m <sup>2</sup> )	20 year Design E80'S z. 10'	material	date contractor	depth	net bitumen	cement
Bonteheuwel Avenue	Bonteheuwel	1710 11800	3	80 asphalt 190 Ferricrete sand	11/95 Concor	200	1.5 %	1.0 %
Silverstream Road	Manenberg	545 6750	< 1	40 asphalt 350 calcrete sand	4/96 Rundel	150	1.2 %	2.0 %
Signal Hill Road	Cape Town	2050 14400	3	40 asphalt 50 per macad 150 dec. shale	4/97 Rundel	220	1.5 %	2.2 %
Gunners Circle (phase 1)	Epping	1080 13900	9	50 asphalt 75 per macad 200 ferricrete sand	4/97 Rundel	250	1.5 %	2.0 %
Lansdowne Road (phase 1)	Philippi	3230 22900	10 - 15	90 asphalt 250 CTSB hornfels 250 calcrete/ sandstone dark grey sand	3-6/98 Concor	200	1.6 %	2.0 %
Miller Street	Nyanga	520 6000	1 - 3	40 asphalt 200 - 300 calcrete / hornfels light brown sand	3-6/98 Concor	250	1.6 %	1.5 %
NY 1	Guguletu	210 1480	3	50 asphalt 150 ferricrete light brown sand	3-6/98 Concor	210	1.6 %	2.0 %

eMyodo	Nyanga	120 830	< 1	15 chip & spray 220 hornfels sand	3-6/98 Concor	250	1.6%	1.5%
Washington Street	Langa	650 6500	3	40 asphalt 350 hornfels light brown sand	3-6/98 Concor	235	1.6%	1.5%
Great Dutch Street	Nyanga	210 1500	< 1	30 asphalt 200 hornfels 120 shale light brown sand	3-6/98 Concor	175	1.5%	1.5%
Lukannon Drive	Strandfontein	3450 21400	< 1	10 chip & spray 200 ferricrete light brown sand	3-6/98 Concor	200	1.6%	2.0%
Acacia Road	Parkwood	410 2300	1	40 asphalt 150 ferricrete 120 hornfels brown sand	3-6/98 Concor	210	1.6%	2.0%
Sipika Road	Nyanga	180 1230	< 1		3-6/98 Concor	200	1.6%	1.5%
Vanguard Drive	Wingfield	3390 34200	> 15	50 asphalt 300 hornfels ferricrete	3-7/99 Raubex	300	2.0%	2.0%
Lansdowne Road (Phase 2)	Phillipi	3300 25600	10 - 15	60 asphalt 300 hornfels varies / sand	3-7/99 Raubex	300	2.0%	2.0%
Gunners Circle	Epping	2820 35900	9	50 asphalt 120 pen macad 350 ferricrete	3-7/99 Raubex	300	2.0%	2.0%
Hlati Street	Nyanga	315 1740	< 1	15c&s 200 hornfels 380 sandy calcrete	3-7/99 Raubex	150	2.0%	2.0%

Zweitsha Drive	Nyanga	420 3000	2	40 asphalt 300 calcrete varies	3-7/99 Raubex	200	2.0 %	2.0 %
Punt Road	Philippi	3760 22600	< 1	15 c&s 100 calcrete 300 sandstone	3-7/99 Raubex	150	2.0 %	2.0 %
Camp Road	Stranfontein	920 5600	< 1	15 c&s 150 hornfels sand	3-7/99 Raubex	200	2.0 %	2.0 %
Rhodes Drive	Cecelia	4500 27000	1 - 3	80 asphalt 150 laterite 300 telford pack	6/99 Raubex	200	1.8 %	2 %
Spine Road	Strandfontein	5380 68000	3	40 asphalt 150 hornfels base 150 hornfels sub sand	3-6/2000 Concor	250	1.2 %	1.5 %
Hans Aschenborne Street	Woodlands	3740 31000	<1	50 asphalt 120 hornfels base 120 hornfels sub sand	3-6/2000 Concor	150	1.2 %	1.5 %
Old Lansdowne Road	Philippi	1670 4800	1	80 asphalt 120 hornfels 150 hornfels sub sand	3-6/2000 Concor	250	1.2 %	1.5 %
Ny 78	Nyanga	420 4000	< 1	20 asphalt 60 BTB 300 hornfels sand	3-6/2000 Concor	150	1.2 %	1.5 %
Ny 6	Nyanga	250 2300	< 1	20 asphalt 80 BTB 220 hornfels sand	3-6/2000 Concor	200	1.2 %	1.5 %

# APPENDIX 9

DCP survey and analysis

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# DYNAMIC CONE PENETRATION TEST



**NINHAM SHAND  
CONSULTING ENGINEERS**

**PROJECT :** CITY OF CAPE TOWN-SIGNAL HILL

**TESTED:** ZM

**PROJECT NO:** 6800/0/VQ/R95

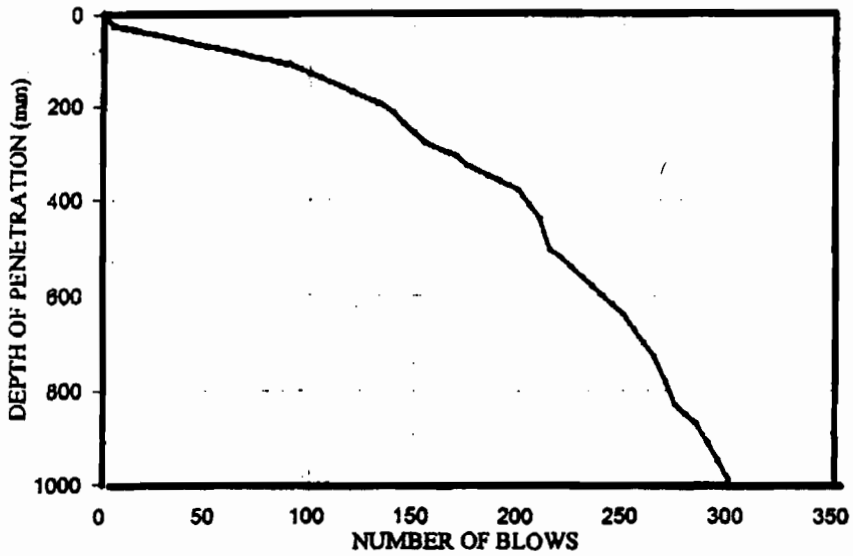
**DATE:** 14/08/00

**TEST NO:** 2

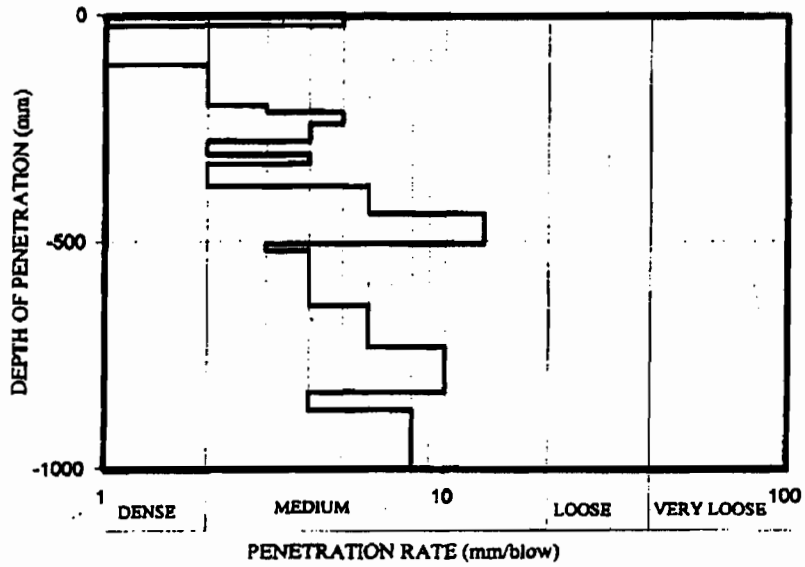
**FILE NO:** 6800/0/VQ/R95

**SV** 1000 m

## PENETRATION DEPTH VS BLOWS

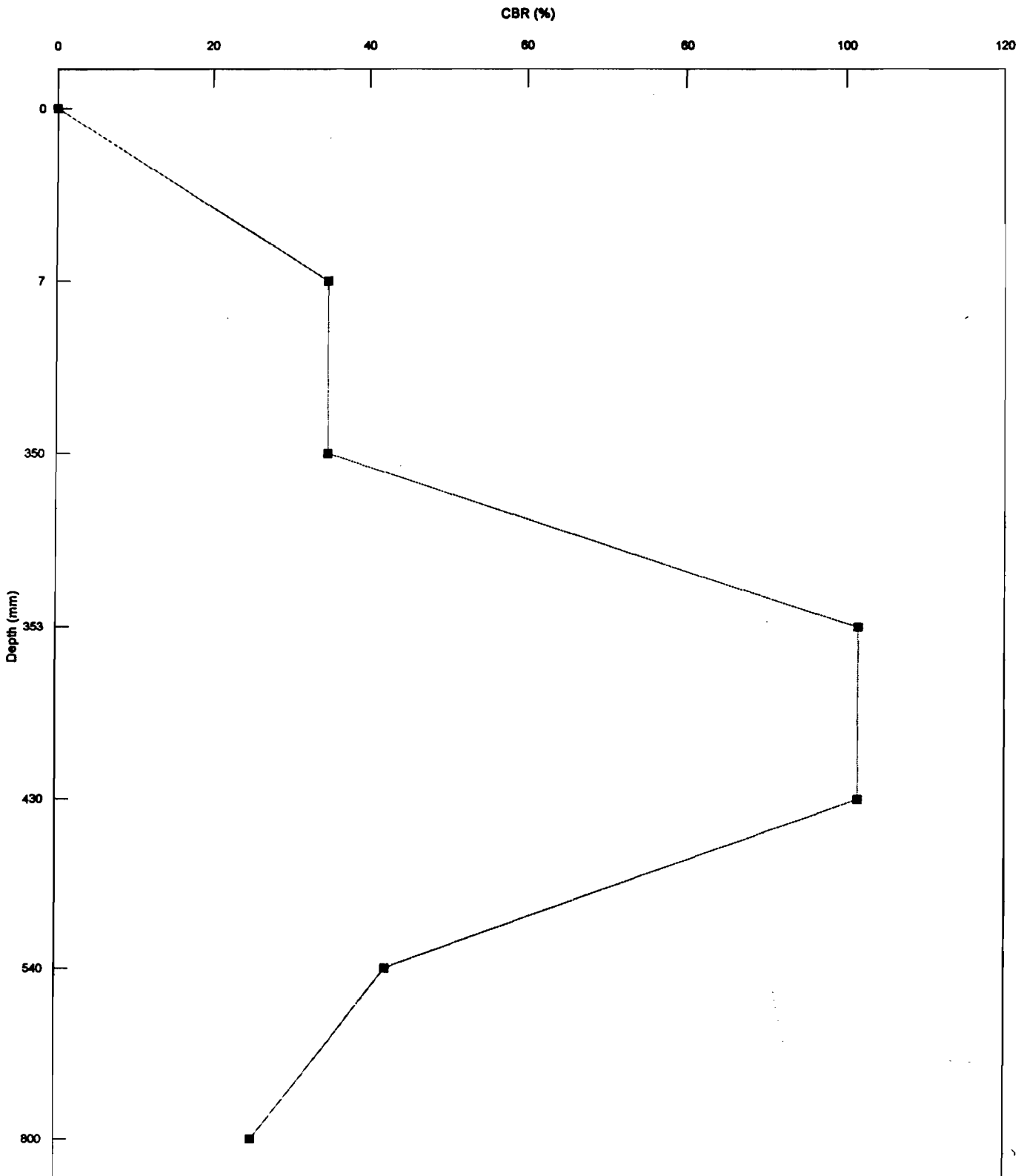


## PENETRATION RATE VS DEPTH



# CBR vs. DEPTH

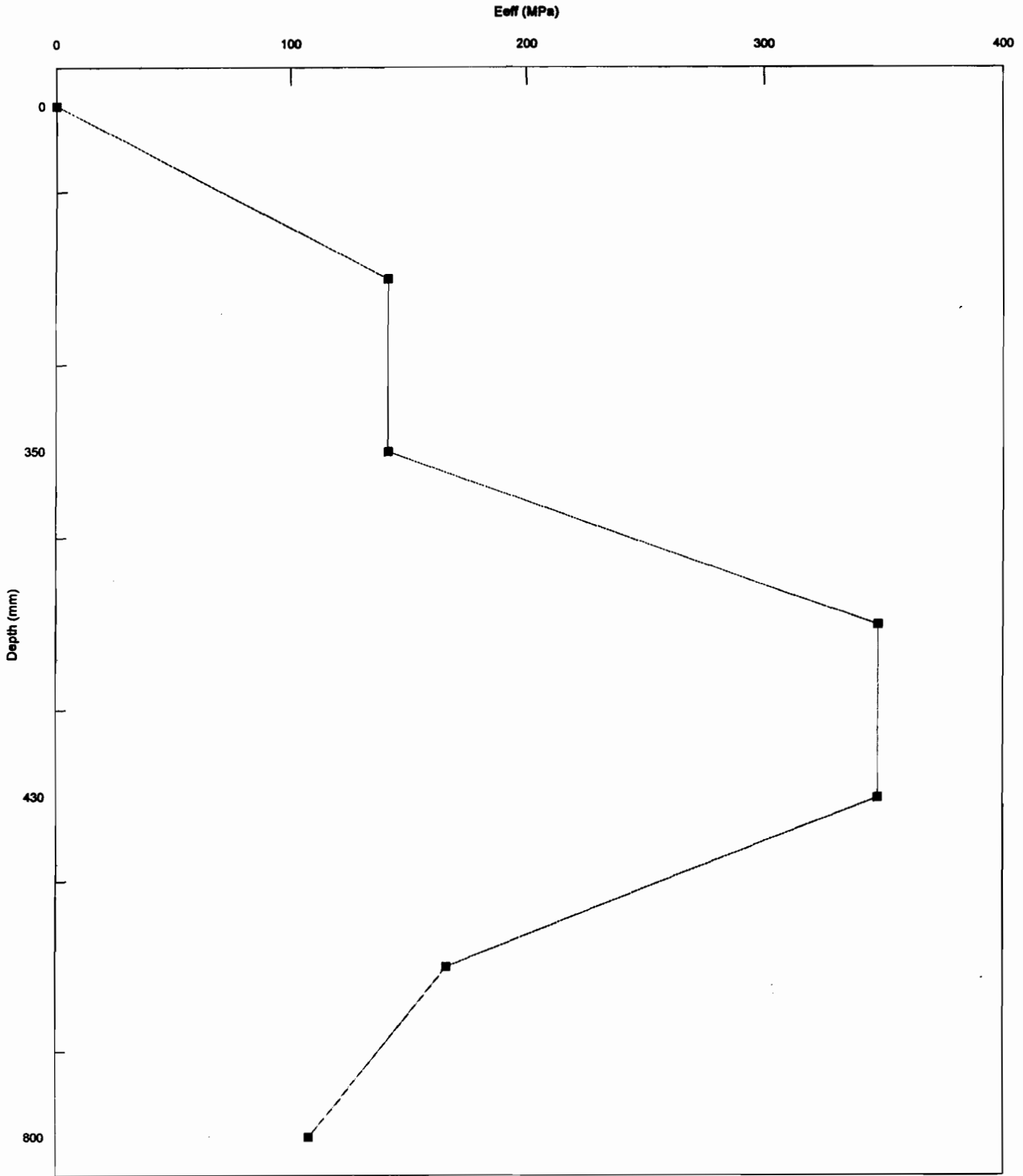
Signal Hill Road



Test no 1

# Elastic Modulus (Eeff) vs. Depth

Signal Hill Road

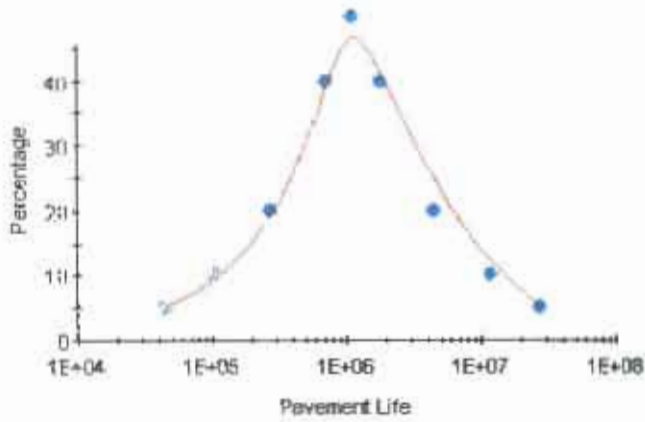


Test no 2

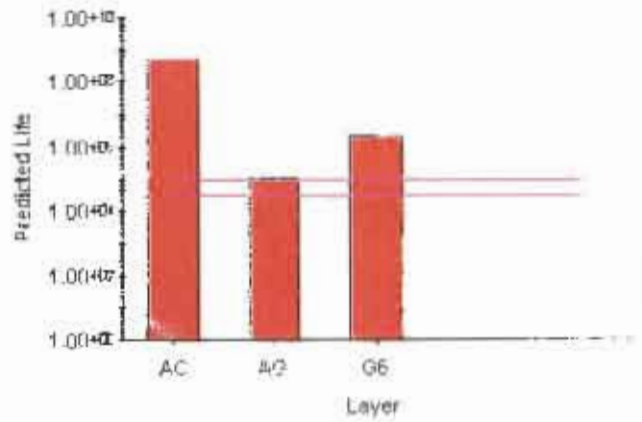
# APPENDIX 10

**PADS sample output [36]**

Approximate Pavement Life Distribution



Estimated Layer Bearing Capacity



Layer Bearing Capacities

Layer	Life	Cemented Life
AC	5.57111e+08	
AG	104324	
G6	2.33047e+08	

Crushing in Cemented Layers

Crush Int.	Adv. crushing

Calculate

University



## APPENDIX 11

TRH 4 pavement design example

PAVEMENT STRUCTURE DESIGN BY TRH 4

DESIGNER: N. ZONDETTI  
DATE:

SOURCE	ROAD	FROM TO	REMARKS
	SIGNAL HILL	MORONG TO	
	SUBURB CAPE TOWN		
	REASON FOR DESIGN REHABILITATION		
TRH 4 table 1	ADT (evu) = 900	DATE OF TRAFFIC SURVEY	27/10/95
	ADHT (x) = 40	ROAD CATEGORY = B	
table 3	STRUCTURAL DESIGN PERIOD = 20		
table 3	LOAD EQUIVALENCY FACTOR (F) = 2		
table 9	TRAFFIC GROWTH FACTOR (Gx) = 1.31	3%	
table 10	CUMALATIVE EQUIVALENT TRAFFIC (Fy) = 9045		
table 11	LANE DISTRIBUTION FACTOR (Be) = 1		
	CUMALATIVE EQUIVALENT TRAFFIC :		
	Ne = Gx . Fy . Be . F . x		
	Ne = 1.3 x 10 <sup>6</sup> ES <sup>6</sup> (3%)		
	Ne = 5.4 x 10 <sup>6</sup> ES <sup>6</sup> (8%)		
table 4	TRAFFIC CLASS = E3		
table 18	SUBGRADE CBR = 10		
	SELECTED LAYERS OR SUBGRADE TREATMENT: N/A		
	PROPOSED STRUCTURE		
	1 30mm AG 155mm STB 150mm GS	2	3