SAME-HIMO ROAD, TANZANIA
LONG TERM MONITORING OF A PAVEMENT MADE OF NATURAL GRAVEL STABILISED WITH FOAMED BITUMEN

by

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ABSTRACT

The bitumen foaming technique by adding water to hot bitumen and thereby causing a temporary expansion to 15-20 times of original volume can be employed for the purpose of greatly improving the coating properties of the bituminous binder in a mix. The improved coating takes place to an extent that even hard penetration grade bitumen can mix intimately with cold aggregates. Before 1990 some use of this technique to produce bituminous mixes has been seen in the United States, the Scandinavian countries, to some extent in Australia and South Africa, and possibly on a limited scale elsewhere. The principles of the foaming technique have been known for decades, however, a widespread use of the method has been limited, partly due to operational constraints.

During the 1990s the bitumen foaming technique has had considerable use in large scale pavement rehabilitation and new construction in Tanzania and Zambia, amounting to well over one million tonnes of placed material. The Same-Himo project in northern Tanzania was a pilot project on large scale utilisation of the method, that lead to its increased use in the 1990s. The Same-Himo project used recycling of the existing pavement by in-situ milling and mixing and in parts of the project by premixing natural gravel in a cold process for production of base course materials. The project road is 82 km long and since the time rehabilitation was completed in 1992 the road has undergone monitoring of pavement performance. The monitoring was conducted by Central materials Laboratory, now TanLab, under the programme for institutional cooperation between Ministry of Works and the Norwegian Public Roads Administration, financed bilaterally by the Government of Tanzania and NORAD. The monitoring programme included core sampling and laboratory testing, measurement of rutting, roughness, cracks and deflection, in addition to visual inspection and collection of traffic data and climatic data.

The result of monitoring the pavement performance over the road's initial eight years in service since completed construction has shown no structural or functional defects in the pavement. One of the monitored sections has had a steady development of surface cracks, while the others have not had this development. The crack development has not had adverse effects on riding quality or rut developments, and the development of the cracks does not correlate with any other performance parameter. This may lead to a conclusion that the cracks are related to the construction method or conditions in the earthworks. The bituminous binder has hardened severely over the years, but no relation to any

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pavement performance parameters can yet be seen. The E-Modulus of the bituminous base course, measured by testing indirect tensile strength of core samples, increased considerably during the first 3-4 years in service, but has since that time decreased, and appears to have levelled out after eight years in service at values just above the design value for the pavement. Further monitoring is required to confirm the development of E-Modulus of the base course.

1 INTRODUCTION

1.1 Background

Expansion of bitumen into foam by the use of water in order to enable mixing with cold aggregate is a method that has been known for decades and has been used in construction of pavement layers world-wide. Potential problems during mixing and laying, that may have caused reluctance to use the foaming method more widely, but were largely overcome on the described project. The roads in these projects were constructed successfully on a large scale in Tanzania and Zambia in Africa between 1990 and 2000. The total length of these roads were more than 350 km of base course of bitumen sealed roads on four projects, plus 340 km of extensive repairs of existing asphalt pavements on one project and the pavements have all performed well. The method is now included in the design standards of Tanzania, ref in 1999. The Same-Himo road rehabilitation financed by Norad was the pilot project that gave the required experience and confidence to embark on further projects. Monitoring of the pavement of this road was therefore of great importance in order to get a rational measure of performance and thereby gain confidence in the method, and to detect any possible difficulties that may arise from using the method.

1.2 Same-Himo Project History

The Same-Himo road rehabilitation project was a part of the Tanzanian multi donor financed Sixth Highway rehabilitation program package of 1980s. The road is a section of the North -Eastern corridor of the Tanzanian Trunk roads network. The original 6.0m wide existing road pavement was constructed in 1968/69 consisting of cement stabilised base course and a double surface dressing. Up to the year 1989 this road had deteriorated to the extent that it required rehabilitation.

The initial rehabilitation design was conventional using a crushed stone base course. This design was revised and amended with technical advice from Norwegian Public Roads Administration. The later design comprised of bitumen stabilisation of the base course by recycling and partly by using cold premixed material. This method was initiated as a pilot project intended to introduce the cold bitumen stabilisation technology to Tanzania with the view of both technical and economical benefits to the road industry in the country.

When the road was completed in 1992 it was seen necessary to carry out a long term monitoring of performance of this newly introduced technology for the benefit of the Ministry of Works and the Tanzanian roads construction industry as a whole. The Monitoring programme was launched in September 1993 and has been implemented as one of several projects under the institutional cooperation between the Central Materials Laboratory (now TanLab) of Ministry of Works- and the Norwegian Public Roads Administration.

1.3 Purpose and Contents of the Paper

The paper contains records of the pavement type, traffic, climate and performance in the initial eight years the Same-Himo road has been in service. The purpose of this paper is to disseminate this information by sharing experiences gained from the design and construction, and reporting the performance of the pavement. This information would be to the benefit of those engaged in design, construction and maintenance of projects where this method could be a viable alternative and thereby provide cost savings.

2 THE FOAMING TECHNIQUE

2.1 Description

Foaming of bitumen is carried out in a continuous process, essentially by introducing small amounts of water into hot (175°C) bitumen under high pressure. The vapour pressure in the super heated and finely distributed water particles causes a temporary 15-20 fold expansion of the bitumen when released into atmospheric pressure through the spray nozzles ('foaming'). The principle of the Nodest method for foaming used on the project is shown in fig. 1.

The water (~5%) added to the bitumen in the foaming process is instantly released as steam during mixing and has no other significant effect on the properties of the final product than by temporarily modifying the bitumen.

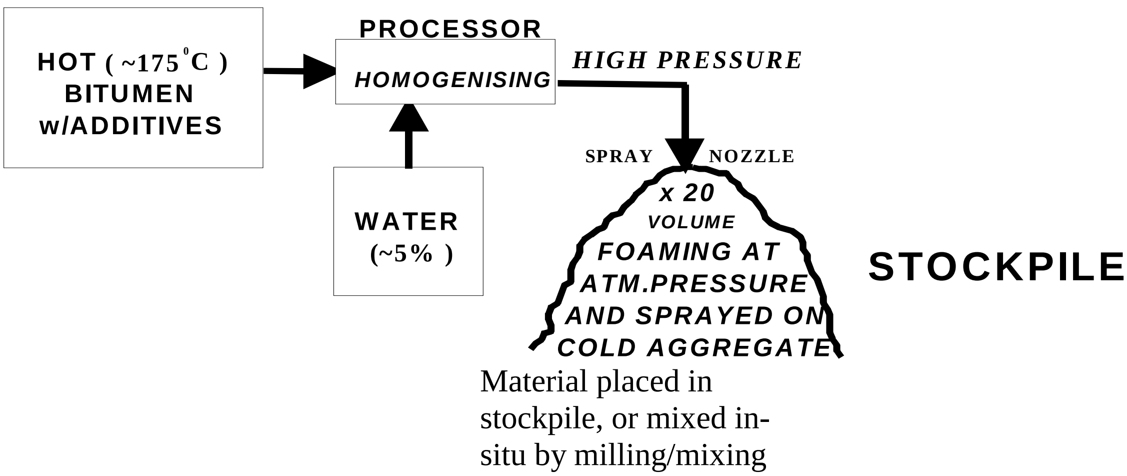


Figure 1: Principle of Bitumen Foaming

2.2 Advantages - Disadvantages

The use of bitumen foam in cold mix methods has the following advantages compared to alternative cold techniques:

- Foamed bitumen allows for a wider range of aggregate qualities, such as higher fines contents, compared to bitumen emulsion (Myre 1997).
- The use of foamed bitumen gives easier control of the moisture content compared to bitumen emulsion which introduces large amount of water into the layer, causing sensitivity during construction (Overby 1996).
- The material does not give prolonged instability in the curing period (Johansen 1997).
- There are less environmental disadvantages compared to cutback bitumen which requires large amount of potentially harmful solvents.

- Both bitumen emulsion and cutback bitumen will absorb a larger proportion of the binder in the cases where aggregates of poor quality has to be used.

Compared to hot mixed materials a major cost saving is in the reduction of energy costs and the opportunity to use existing pavement layers and generally to accept a poorer quality of aggregate without adverse effects. Bitumen foaming does however require specialised equipment, which may not be widely accessible, thereby lead to less competition in contract bidding.

3 CONSTRUCTION

3.1 Methodology

On the Same-Himo road, part of the pavement rehabilitation method was by milling the existing pavement made of cement stabilised base course and natural gravel subbase, and subsequently laying the mixture with pavers. The milling machine is built on the chassis of a motor scraper fitted with an additional milling drum and a bitumen mixing unit for addition of predetermined amounts of bitumen to the milled material. The milling and admixture of water and foamed bitumen takes place in a continuous process using large equipment capable of milling to the design depth of up to 175mm at a full lane width. The bitumen content. In this operation, the process is governed by several factors including the milling depth, that may vary depending on variations in the hardness of the old pavement. Unevenness and deformation of the existing pavement cannot easily be corrected by the process, but requires compensation by addition of material prior to milling.

Part of the project was constructed with a base course made from natural gravel premixed with foamed bitumen in a cold process at the borrow pit, transported to the road and placed with pavers.

3.2 Binder Types

On the Same-Himo road grade 80/100 penetration was used. The aggregate has to be moist at the time the foamed bitumen is admixed and an adhesion agent was added at a rate of 0.8% of the binder in order to give sufficient adhesion.

3.3 Mixing Operations

Being a cold process, the stabilisation with foamed bitumen is eminently suited for milling and in-situ mixing. A premix plant was however commissioned during the Same-Himo project due to problems in achieving correct geometry and a good riding quality using the milling operation, requiring re-milling of the upper part of all constructed base course before the surfacing was placed. The type of plant used for premixing on the project was a high capacity plant of a small and highly mobile type that utilised gravity in the mixing process.

3.4 Pavement Design, Traffic, Cross Section and Climate

The Same -Himo road the old cement stabilised pavement structure together with the surface dressing was milled in one operation and stabilised in-situ by additional of 4.4% bitumen. This is the part of the project where premixed bituminous base course used the same bitumen content. The nominal layer thickness of the base course was 175mm and for premixed material 150mm respectively. The subbase was natural gravel with CBR minimum 30%. Design CBR of the subgrade, minimum 10%.

The design traffic loading was estimated to between 4 and 5 million E80s over a fifteen years design period.

Figures 2 and 3 show the climatic conditions in the area.

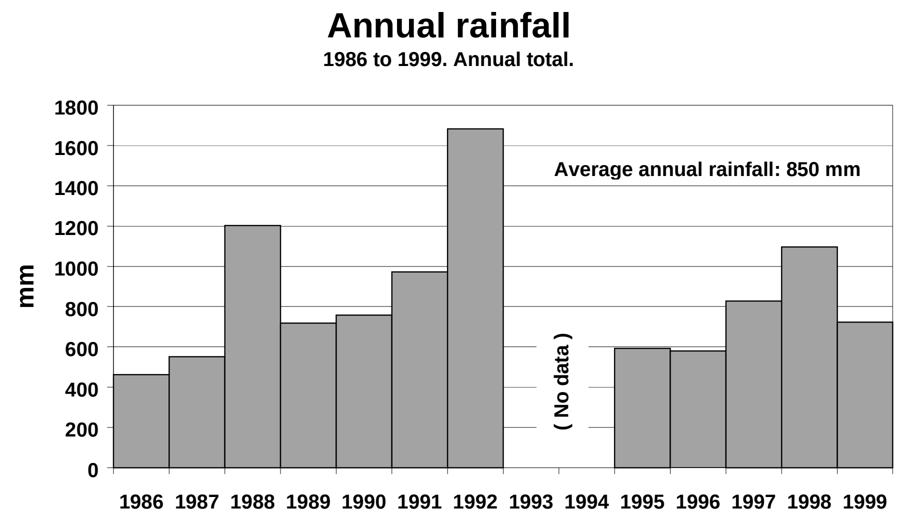


Figure ?

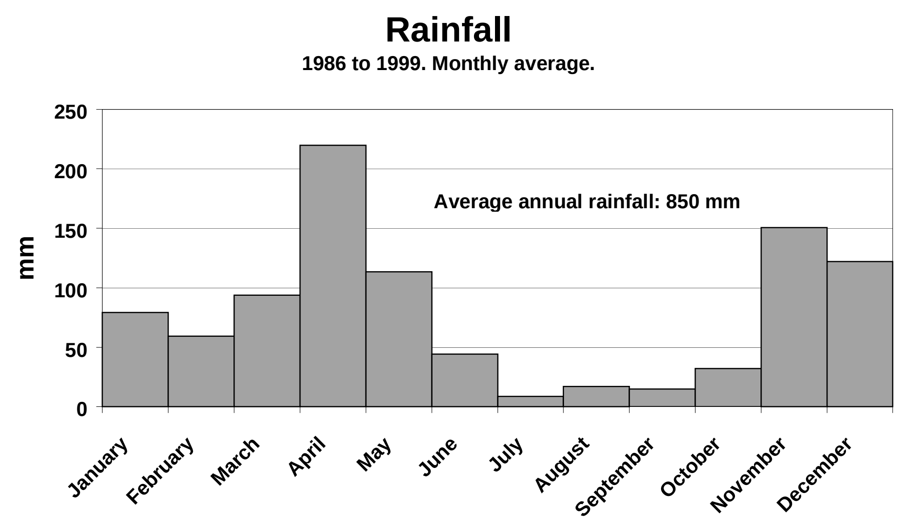


Figure 2. Rainfall data

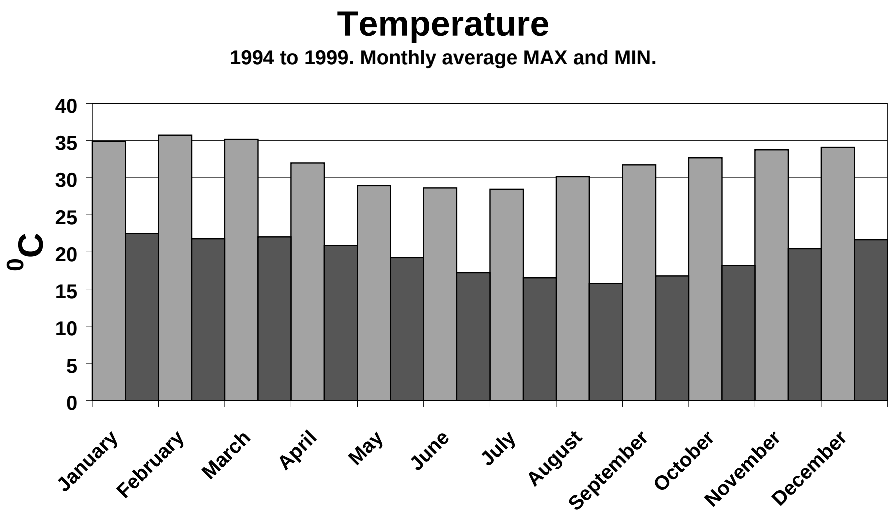


Figure 3. Temperature data

4 TRIAL SECTIONS

Prior to full production of the bitumen stabilisation, trial sections were proposed as a preliminary measure to ensure the concept of bitumen stabilisation was successfully implemented with regard to the prevailing environmental conditions around the project area. These trials were basically meant to address the following:

- Concern: sufficient stability of the bitumen stabilised material?
- Selection: emulsion or foamed bitumen, which were best suited?
- Experience: the practicality of the milling operation in general?

The three trial sections adopted significantly different method of base courses stabilisation and type of materials either in situ or imported. Basically the sub grade materials for all sections were of similar specified properties and mostly were in situ with no fill or cut. Similarly the sub base materials were either scarified existing pavement or imported gravel but basically had similar properties and conformity to requirements of project materials specifications.

The trials were constructed at Lembeni area by milling the existing pavement and mixing with emulsion or foamed penetration grade bitumen 80/100 with target residual bitumen content of 4%. The trial section consisted of six sub sections each 100m long out of which three subsections were stabilised by emulsion and the remaining by foamed 80/100 bitumen. Out of the three sections with foamed bitumen 80/100 pen, two were stabilised to 150mm thickness, of which one had 2% cement added while the third was stabilised to a shallow depth of 75mm. Similar treatment was done to the emulsion sections.

After accelerated trafficking and site observations during and after construction the selection of binder favoured foamed bitumen instead of emulsion, and cement was omitted in the mix as no initial stability problems arose.

5 MONITORING PROGRAMME

5.1 General - Objectives

Bitumen stabilisation technology was new to Tanzanian environment. Consequently, it was essential to gather long-term performance statistical information or data to be used as a basis to make sure the technology is feasibly and correctly adopted and possibly the light to the cost effectiveness on lifetime basis.

In addition to the satisfactory results of short term durability criteria obtained from preliminary trial sections, a long term monitoring programme was set out with the main objective of assessing the long-term durability of the stabilised basecourse layer with regard to prevailing environment in the project area. This programme would also provide information on the appropriateness of the used specifications. Further to this, on positive conclusion from this monitoring, economical analysis to establish the cost effectiveness with respect to Tanzanian conditions can optionally follow.

The programme was launched in late 1993.The monitored program was concentrated on three identified sections each 100m long and one 1km long section. The following parameters were studied:

5.2 Layout of Sections

5.2.1 Location

In accordance to the primary objective of the monitoring program, sections that were included in the monitoring program exist on portions of the road that received either milling operation, free fall stabilised materials or imported and milled material. The sections are:

1. Section 1: km 372 + 200 to km 372 + 300 - 100m long. Premixing technology was applied. In addition section km 371 to 372 were included for a reduced measurement programme.
2. Section 2: km 414+800 to km 414+900 - 100m long. Imported materials were milled together with in situ existing pavement materials
3. Section 3: km 428 + 500 to km 428 + 600- 100m long. Existing pavement was milled in-situ to become base course in the new pavement.

These sections are considered to represent all the three operations of cold bitumen stabilisation technologies used in construction of the road. For each construction method one section (100m long) was selected as a representative for monitoring purposes.

5.3 As-built data

5.3.1 Subgrade and subbase

Investigation and construction testing performed at different stages before and during construction indicated that the subgrade materials at all the three sections comprise of soils with the following nominal properties:
CBR minimm 10% at 93% Mod AASHTO
CBR swell maximum 1.5%
Compaction 93% mod AASHTO

Generally the subbase was either scarified or imported materials from quarries at km 378 or km 409 with typical properties, based on more than 100 tested bulk samples as:
CBR average 40% (4days soaked at 95%mod. AASHTO MDD)

Average Field density = 96.7% Mod MDD
OMC range = 5.6% - 13.1%

Base course

In the case of premixing the base course material a total thickness of 150mm stabilised materials was placed in two equal layers of 75mm each with a thin tack coat in between for proper bonding. The sections where recycling of the existing pavement was employed were milled to a depth of 175mm. Nominal bitumen content 4.4% and design E-moduls minimum 1200Mpa. The construction method for the base course was the following on the three monitored sections:

Km 372	natural gravel premixed with foamed bitumen
Km 414	natural gravel premixed with foamed bitumen
Km 428	milled existing pavement

Typical test results from Marshall testing of the base course material were:

Premixed material	**Low**	**Average**	**High**
Marshall stability (kN)	6	12	20
Av. Flow (mm)		2,2	
Stiffness (N/mm)	1 300	5 300	22 700
Milled material	**Low**	**Average**	**High**
Marshall stability (N)	5	10	21
Av. Flow (mm)		2,67	
Stiffness (N/mm)	1 100	4 200	12 500

6 SPECIAL INVESTIGATION

Within the period when monitoring of the Same - Himo section was in progress one special study for the whole road was performed. After about three years of service of the Same-Himo road up to 1994 the general condition of the road was described as good. In late 1993 towards the end of the projects liability period cracks were observed to start emerging on the surface of the pavement carriageway and also on shoulders. It was reported that these cracks were randomly and erratically distributed along the stabilised pavement and did not follow specific pattern. Furthermore, it was reported that the cracks were more concentrated in the wheel tracks and predominantly on the milled sections. Special investigations were carried out in 1995 with the main objectives of establishing the causes of the defects appearing on the road and determine the implications with regards to future maintenance. The investigations included structural bearing capacity assessment of the pavement through non-destructive testing in the field, i.e. deflection and DCP, laboratory determination of E-modulus of stabilised base course and a quantification of the surface performance indicators.

7 MONITORING PROGRAMME

7.1 Observation Data and Surface Measurements

The main sources of data collected were from field measurements and laboratory testing. The data collection schedule, as set out at the start of the monitoring program required a complete set of all necessary data collected once per year and particularly after rainy season. The monitoring has been carried out on an annual basis and core drilling every second year.

Traffic data were obtained from various sources, such as those conducted by NPRA in April/May 1991 as part of the Same - Himo road rehabilitation project, subsequent surveys by consultants along the Segera - Same road and traffic count data from Regional Engineer -Kilimanjaro conducted in March 1995. In addition the traffic counts were performed by the MOW planning department in 1997 and the axle load survey by Central Materials Laboratory of November 1998. These surveys were done as part of the trunk roads pavement monitoring.

All the above have been utilised to obtain a reasonable estimate of cumulative standard axle load.

Rut depths were measured on wheel paths at identified locations at intervals of 10m. Measurements were done repeatedly at the same location every year. A simple equipment comprising of a nylon string long enough to cross from the centreline to the edge of the carriage way and a standard rutting wedge were used. The rut depth was taken at the location with largest depression across the wheel track.

Visual inspection was performed to cover the whole section in order to capture other deterioration indicators like potholes, ravelling cracks on other locations and bleeding. Observations were mapped on special data sheet in scale and the same data sheet was used every time so that it was possible to record any changes.

7.2 Core Sampling

Environmental attributes have significant contribution to the pavement performance, causing similar type of pavement to behave differently under different environments. Weathering and oxidation causes bituminous materials to become brittle and therefore more susceptible to cracking and disintegration. Once initiated, cracking extends in area, increases in density and severity and eventually potholes may develop. Laboratory testing in the monitoring program required core samples from the stabilised base course. Cores samples were drilled at specific locations through the stabilised base layer in accordance to the predetermined coring schedule set out at the beginning of the monitoring programme.

The coring schedule set out was made such that for every scheduled monitoring 15 cores with 100mm in diameter and at least 150mm in height were drilled from specific locations:

- Two cores from the LHS (side A) outer wheel track drilled at adjacent locations at 200mm.
- Two cores from LHS between the outer and inner wheel tracks similar in adjacent locations
- One core from RHS outer wheel track

Efforts were made to protect the cores from drying out by the use of plastic bags. Given the risk of drying out, and the additional moisture from the coring operation, one may assume that the moisture contents of the cores were overall not very far from the moisture content in-situ. This has however not been confirmed in the field.

7.3 Laboratory Tests

The cores drilled from the stabilised base course were subjected to indirect tensile strength, Marshal testing, extraction and bitumen recovery tests in laboratory. Tensile strength and Marshal stability tests were undertaken to measure any changes in strength of the stabilised base layer over time.

7.3.1 Indirect tensile strength test

The indirect tensile strength involves application of static compressive load across the diametric axis of a cylindrical specimen. Samples are normally conditioned in the oven at 29^{o}C for about 1hr before testing. The total load at failure of the sample is the indirect tensile strength of the particular sample tested.

In this monitoring each core samples, 60m diameter and 150 mm in height (through base layer thickness), drilled from the stabilised base layer were cut along the height into two portions each 60mm high referred to in this report as 0-60mm for the upper portion and 60-120mm for the lower portion. These were the samples for indirect tensile strength test.

The indirect tensile strength is affected by several parameter like voids, moisture content, bitumen content, amount of fines and properties of the binder. In this work these parameters are assumed to have equally spread effects to all tests and therefore have not been analysed separately.

The indirect strength test results were used to compute the E- modulus using the following relationship:

$$E(MPa) = 6.1S + 100 \quad \text{Where } S = \text{tensile strength in kN}$$

Bitumen recovery was performed in Norway, and the recovered bitumen was subjected to penetration, viscosity and softening point test. These are indicative tests for ageing of bituminous materials.

8. RESULTS OF THE MONITORING 1993 - 2000

8.1 Traffic

The cumulative equivalent standard axle is presented in the table below. On average the road section have so far accommodated an estimated equivalent standard axle loads of 2,12 millions which is about 40% of the design E80s of 5.0million.

Table 1: Traffic

	LHS (northbound)	RHS (southbound)
Design traffic, E80 (million)	5,0	-
Accumulated E80 by year 2000 (million)	2,1	1,4
AADT year 1991, at completion	580 with 43% heavy vehicles	
AADT year 2000	870 with 37% heavy vehicles	

8.2 Visual Inspection

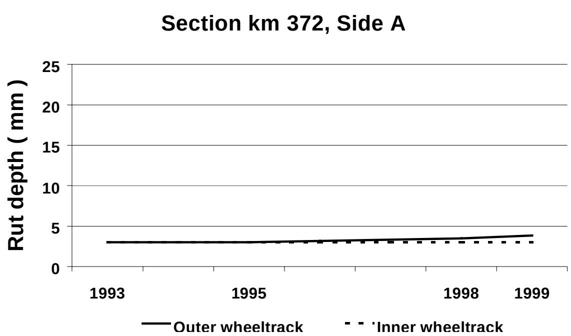
The observations from the visual inspection show no development of potholes and no significant development of cracks, except for section km428 which has had a steady increasing crack development during the monitoring period.

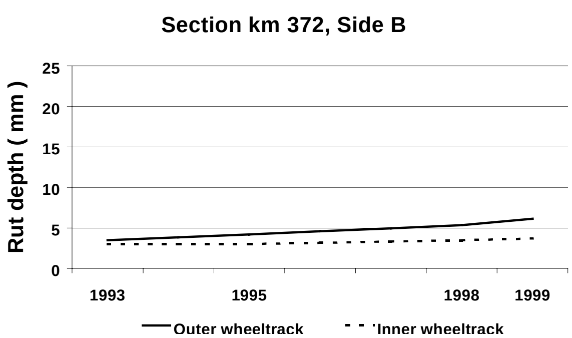
8.3 Rutting

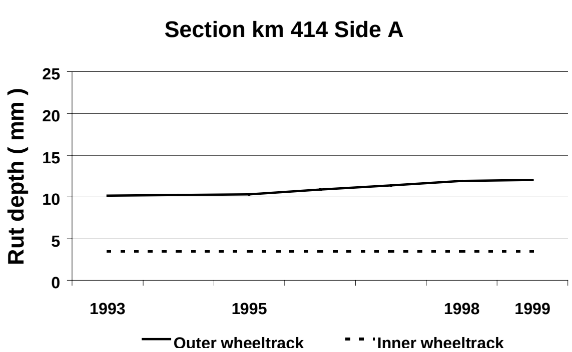
The 90%-ile values of rut measurements are shown in the figures below.

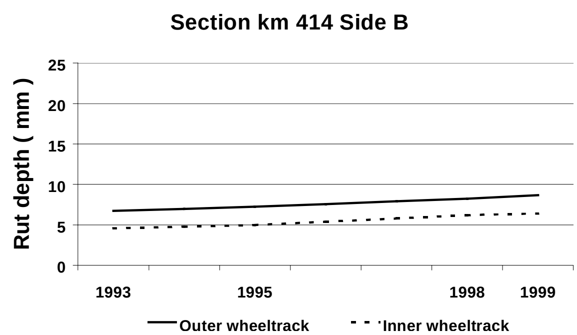
The rut depth data of all three sections shows generally minor changes with time and have not developed to the alarming values as can be seen on the graphical presentation of the 90%-ile rut values. The road is surface dressed and one can assume that part of the rut development is due to normal punching in of the surfacing aggregate over time.

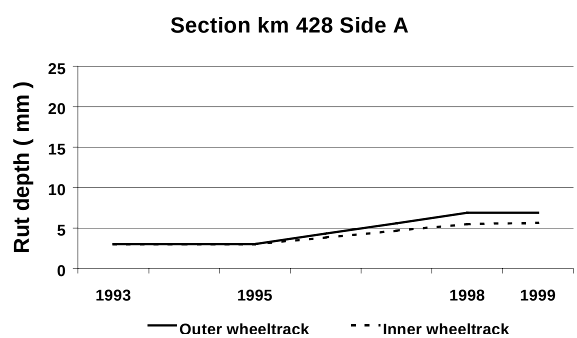
The northbound left hand side lane (Side B) is the heavier loaded of the lanes.

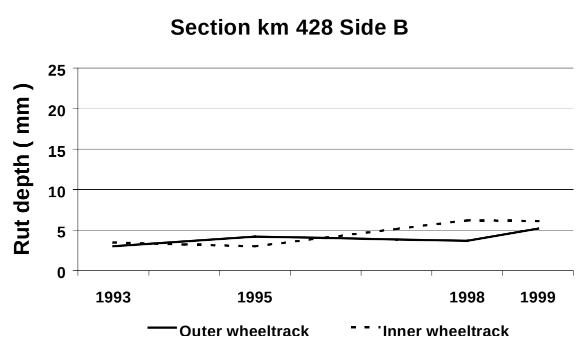






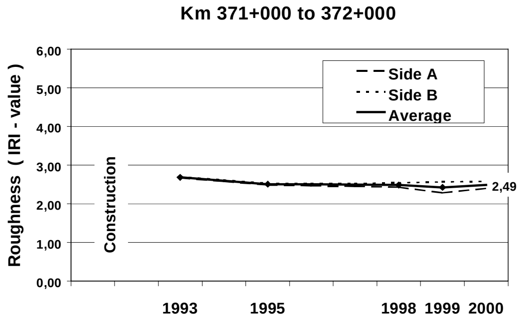


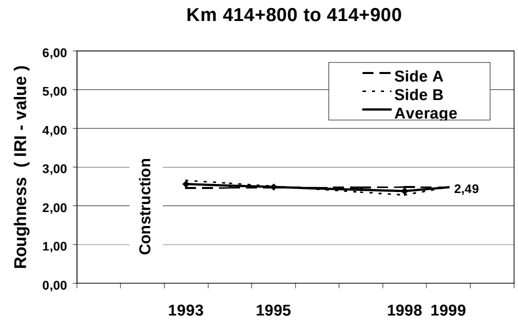


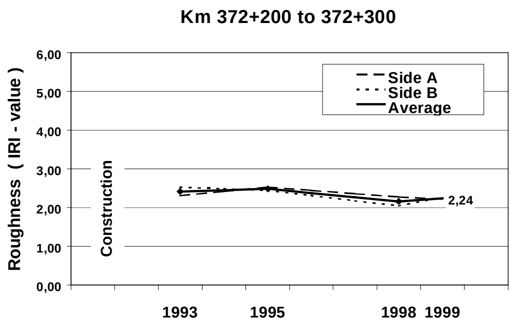


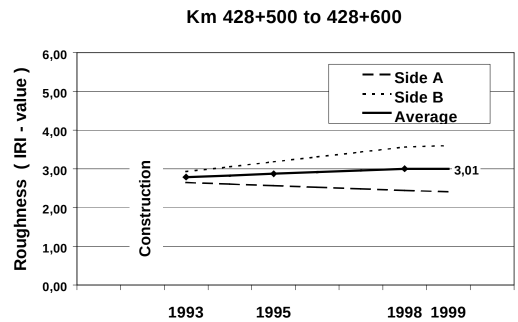
8.4 Roughness

IRI values measured with MERLIN are shown in the figures below. Generally the road surface roughness for the milled and cold premix sections are minimal, falling within IRI of 2 to 3. Section 414.8-414.9 has slightly higher increase on the surface roughness with a highest IRI value of 4.0



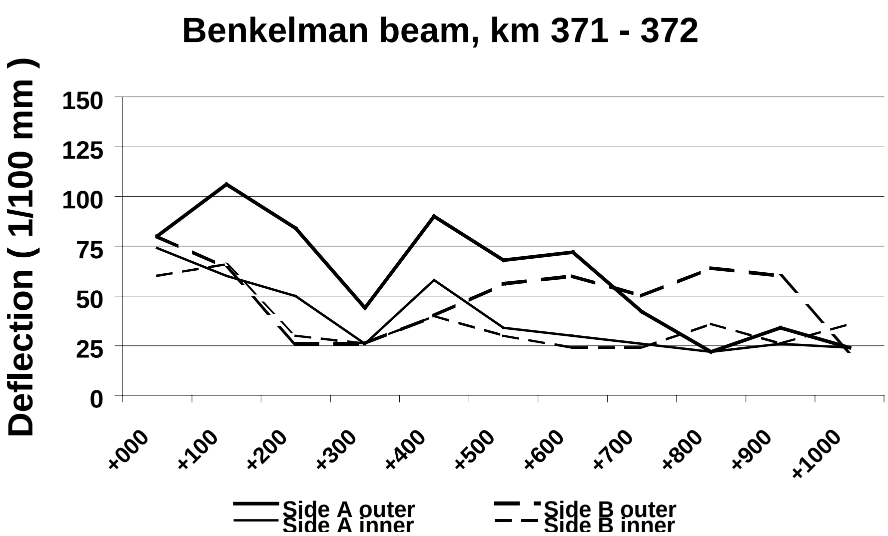






8.5 Deflection

Only section km 371 to km 372 (1 km long) has had maximum deflection measured. The measurements were carried out in 2000 by Benkelman Beam and the rebound method. Axle load was 8100 kg and tyre pressure 590 kPa. Measurement frequency was 100m in outer and inner wheel track respectively.

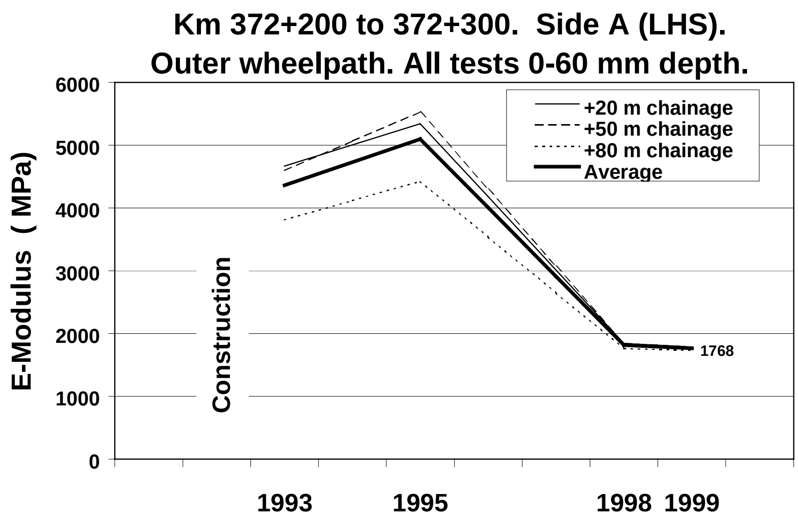


Benkelman beam deflection measurements have only been carried out once, and a trend has therefore not been established. The measured section is 1 km long at km 371 to 372, nearby the monitored section km 372+200 to 372+300 The 90%-ile value for the section is

0,75 mm when assessing all measurements as one statistical lot. The level of deflection values fall into the '***Warning'*** category of the condition rating of Tanzanias *Pavement and Materials Design Manual - 1999* for pavements with 'lightly cemented basecourse'. Assessment of deflection against the criteria for a 'lightly cemented basecourse' is probably reasonable considering the hardening of the binder and likely structural behaviour of the basecourse.

8.6 Measurements of E-Moduli by Indirect Tensile Strength

The figure below shows the typical development of E-Modulus for individual cores. Tests in other locations had a similar development of E-Modulus.

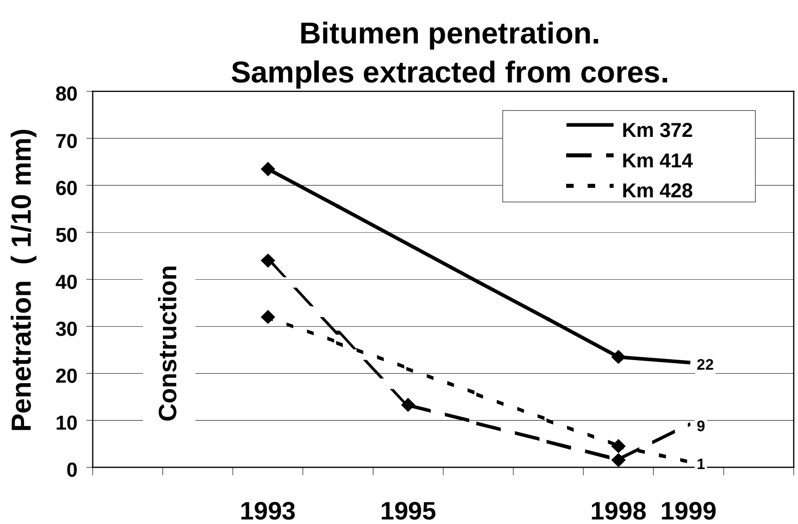


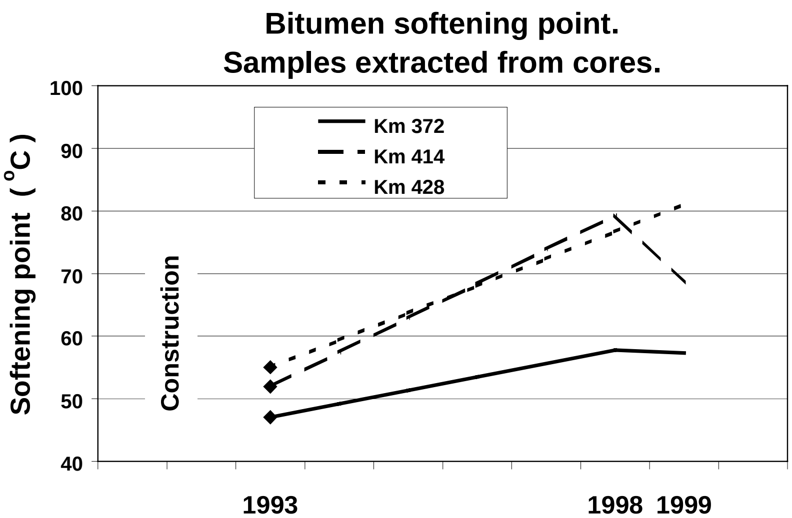
The E-modulus, except for a few cores, was slightly higher in the upper part of the basecourse layer (0 - 60mm) than the lower part of the layer (60-120mm), albeit a very small deifference. This can be explained by better effect from the compaction equipment in the upper part of the layer, and by the re-milling carried out on recycled sections.

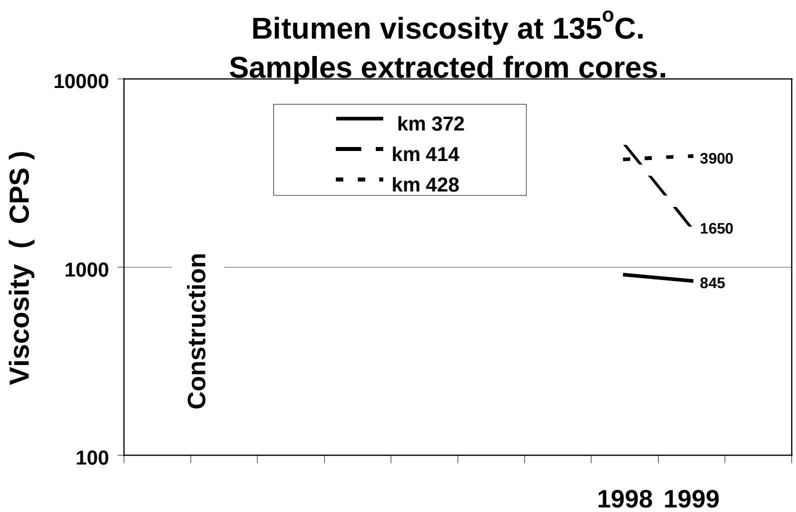
8.7 Bitumen properties

Properties of bitumen recovered from the stabilised base layer were tested in the laboratory for each of the four monitoring session reported in this work**.** All tests were carried out in accordance to ASTM standard procedures. The results of this test for all three sections are as shown in the figures below.

Penetration Test







Bitumen penetration was found to decline at unexpectedly high rate for all sections, and the values that are recorded at the last coring monitoring programme in 1999 are very low. Softening point and viscosity of the recovered bitumen was increasing with age against the decreasing penetration as expected.

9 CONCLUSIONS

9.1 Performance vs. Traffic

By year 2000 the traffic loading in terms of E80 has reached just above 2 millions since construction in the most heavily loaded lane (northbound), amounting to approximately 40% of the design traffic loading. The measured performance parameters do not show any difference between the lanes that can be related to axle loading except for rutting on section 414 where there are slightly higher values in the more trafficked lane.

9.2 E-Modulus

There was a sharp increase in E-moduli of the bituminous basecourse during the first 3 years in service. Thereafter the values declined, reaching a level approximately at the minimum design value after 6 to 7 years in service. From this time the decline in E-modulus appears to have levelled out. All tested core samples show the same pattern of changing E-modulus over time regardless the depth in the layer, or horizontal position on the road.

9.3 Binder hardening

The binder has hardened gradually since the time of construction and after 7 years in service reached very low penetration values. Oxidation process normally attacks the bituminous materials on the exposed surface. It is dependent on the surface area of the materials, which in the case of foamed bitumen with aggregates with high fines contents may be very high. A combination of thin film coating and high void contents contributes to the rapid hardening of the bitumen in the stabilised base course at Same-Himo.

9.4 Deflection

Deflection measurements have only been carried out once, and a trend has therefore not been established. The level of Benkelman beam deflection values fall into the '***Warning'*** category of the condition rating of the Pavement and Materials Design Manual - 1999 for pavements with 'lightly cemented basecourse'. Assessment of deflection against the criteria for a 'lightly cemented basecourse' is probably reasonable considering the hardening of the binder and likely structural behaviour of the basecourse.

9.5 Roughness

There has been no tendency of change in surface roughness since the time of construction and the measured values fall into the category '***Sound'*** in the condition rating in the Pavement and Materials Design Manual - 1999.

9.6 Rutting

There has been a slight and gradual increase in rutting since the time of construction surface roughness since the time of construction, from category '***Sound'*** approaching '***Warning'*** after 3 to 7 years in service. This assessment is made against the condition rating of the Pavement and Materials Design Manual - 1999. It is however possible that the increased rutting, albeit low values, is caused by a punching-in of the surfacing aggregate into the basecourse, and therefore may not have any significance to the performance of the pavement. Contradicting this view is the fact that the increase in rutting values had not levelled out after a length of time in service, during which there had been considerable hardening of the binder in the basecourse.

9.7 Cracks and visual inspection

Visual inspection and measurements of cracks indicate there has been a development of hairline surface cracks on the sections, but there is considerable difference in development of cracks between the sections, and the one constructed by milling of the existing pavement is by far the most severely cracked. The remaining section show only minor cracking. Construction method an subsoil conditions may have had an effect on crack developments.

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