BITUMEN FOAMING – AN INNOVATIVE TECHNIQUE USED ON A LARGE SCALE FOR PAVEMENT REHABILITATION IN AFRICA. CASE STUDY: SAME-HIMO MONITORED PILOT PROJECT.

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Abstract

The bitumen foaming technique by adding water to hot penetration grade bitumen, and thereby causing a temporary expansion to enable coating of cold aggregate, was used in a pilot project on a large scale on the Same-Himo road in Northern Tanzania, reconstructed in the period 1990 to 1992. Pertly natural, screened, gravel, and partly milled old cement stabilised pavement materials, were stabilised using a bitumen content of 4.4% applied without any addition of cement filler.

A comprehensive pavement monitoring programme has been on-going since construction of the Same-Himo road, and the last recordings were carried out late in 2003. The following are conclusions of the findings after the pavement monitoring:

• The pavement utilising natural gravel base course stabilised with foamed bitumen has performed very well on a heavily loaded trunk road in Tanzania. The pavement is currently in an excellent condition.
• The pavement on the Same-Himo road is currently near the end of its 15 years design period and has almost received the 5 million E80s it was designed to withstand.
• The pavement has received no resealing or other periodic maintenance since construction.
• There has been no pothole development on the road.
• There is no excessive development of rutting or surface roughness on the road.
• Sealing of individual cracks has been undertaken on individual sections.
• The pavement utilising natural gravel stabilised with foamed bitumen has performed very well throughout most of its design period on a heavily loaded trunk road in Tanzania.

Following the Same-Himo pilot project the bitumen foaming technique has had considerable use in large scale pavement rehabilitation and new construction in Tanzania and Zambia, during the 1990-ies, amounting to well over one million tonnes of placed material (Appendix 1). The method was subsequently adopted in the Tanzania Pavement and Materials Design Manual-1999, to which a comparison with the Asphalt Academy Manual of South Africa has been made in the paper, albeit only for the purposes of illustrating the variety of approach.
1 INTRODUCTION

1.1 Background

Expansion of bitumen into foam by the use of water, a method to enable bitumen to be mixed with cold aggregate, has been known for decades and has been used in construction of pavement layers world-wide. 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. Potential problems during mixing and laying may however have caused reluctance to use the foaming method more widely than what is the case. In 1990 a pilot project was constructed in Northern Tanzania, where 4.4% foamed bitumen was used in recycling as well as new construction of the base course. The project road was a 82 km long part of the trunk road linking Tanzania to Kenya and is receiving heavy traffic loading.

The Same-Himo road rehabilitation was a pilot project constructed on a full scale and gave the required experience and confidence to embark on further projects using the same technology. The performance of this pavement has been monitored since construction in order to obtain 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. This pavement is now approaching the end of the 15 years design period.

Meanwhile road pavements have been constructed successfully using similar technology on a large scale in Tanzania and Zambia between 1990 and 2000. The total length of these roads were more than 350 km of base course for bitumen sealed roads on four projects, plus 340 km of extensive repairs of existing asphalt pavements on one project. The method is now part of the design standards of Tanzania and was included in the Pavement and Materials Design Manual-1999.

1.2 Scope and purpose of the paper

This paper contains records of the pavement type, traffic, climate and performance in the initial 13 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 stabilisation with foamed bitumen could be a viable option and thereby give cost savings.

2 SAME-HIMO PROJECT HISTORY

The Same-Himo road rehabilitation project was a part of the Tanzanian multi donor financed Sixth Highway Rehabilitation Programme package of the 1980s. The road is a section of the North-Eastern corridor of the Tanzanian Trunk roads network and is part of the SADC regional road network. The original 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 (NPRA). 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 and stakeholders 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. 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/Tanroads and the Norwegian Public Roads Administration.

3 TECHNOLOGY

3.1 The foaming technique

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.

![Diagram of Bitumen Foaming Process]

Fig.1: Principle of Bitumen Foaming

3.2 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.

3.3 Construction

On the Same-Himo road, part of the applied pavement rehabilitation method was milling of the existing pavement made of cement stabilised base course and natural gravel subbase, and subsequently laying the mixture with pavers, see Fig. 2. 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 is governed by several factors, amongst others 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.

Fig. 2: Milling the existing pavement (of old cement stabilised gravel), and admixture of foamed bitumen to a depth of 175 mm in half road width (photo from Same-Himo).

Fig. 3: Production of premixed material by admixture of foamed bitumen in a high-capacity ‘Free-fall’ mixing plant.
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. See Fig. 3.

On the Same-Himo road bitumen penetration grade 80/100 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.

Being a cold process, the stabilisation with foamed bitumen is eminently suited for milling and in-situ mixing. A premix plant was however the 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.

4 PAVEMENT DESIGN, CROSS-SECTION, CLIMATE AND TRAFFIC

4.1 Same - Himo road

On the Same - Himo road the old cement stabilised pavement structure - including the surface dressing - was milled in one operation and stabilised in-situ by additional of 4.4% bitumen, the same amount as where premixed bituminous base course of foamed bitumen was used. The nominal layer thickness of the milled 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%. A double surface dressing was applied directly on the bituminous base course. Typical crossection is shown in Fig. 4, climatic data are shown in Fig. 5.

![Typical crosssection, Same-Himo road](image)

**Fig. 4: Typical crosssection, Same-Himo road**

![Rainfall and Temperature](image)

**Fig. 5: Climatic data, Same-Himo**
Estimated design traffic loading: Close to 5 million E80s over a fifteen years design period. This traffic loading is soon reached towards the end of the design period, see Fig. 6. The pavement has received a considerable amount of severely overloaded axles in the early part of the design period.

Accumulated E80s in heaviest loaded lane. Entire design period.

Design value: 5 millions

![Traffic loading, Same-Himo](image)

**Fig. 6: Traffic loading, Same-Himo**

4.2 Illustration of the Tanzanian design catalogue vs. the South African

Table 1 shows the design requirements for pavements with foamed bitumen base course given in the design catalogue of the Tanzania Pavement and Materials Design Manual-1999. These have been partly based on the experience from the monitoring of the Same-Himo road in addition to other main road projects in Tanzania that form the basis for design of pavements with 80 to 125 mm base course. The empirical basis for design with 60 mm base course is mainly the use on access roads with low traffic in the Northern part of the country. A comparison to the design catalogue of the Asphalt Academy is shown in order to illustrate the approximate levels of thickness design. A direct comparison of pavement strength is not the intention in this paper and is not calculated since both design standards set out own conditions regarding support from subbase/subgrade, type of foamed bitumen mix, material standards, road category, type of traffic and performance.

<table>
<thead>
<tr>
<th>Design Traffic, million E80s</th>
<th>Asphalt Academy, RSA base course layer thickness (mm)</th>
<th>Design Traffic, million E80s</th>
<th>Tanzania standard base course layer thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001 - 0.003</td>
<td>75</td>
<td>0.003 - 0.01</td>
<td>100</td>
</tr>
<tr>
<td>0.01 - 0.03</td>
<td>100-125</td>
<td>0.03 - 0.1</td>
<td>100-125</td>
</tr>
<tr>
<td>0.1 - 0.3</td>
<td>100-150</td>
<td>0.2 - 0.5</td>
<td>60</td>
</tr>
<tr>
<td>0.3 - 1.0</td>
<td>100-175</td>
<td>0.5 - 1.0</td>
<td>80</td>
</tr>
<tr>
<td>1.0 - 3.0</td>
<td>125-175</td>
<td>1.0 - 3.0</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 - 10</td>
<td>150</td>
</tr>
</tbody>
</table>


5 MIX DESIGN, MATERIALS AND QUALITY CONTROL

5.1 Same - Himo road

Typical mix design requirements were the following values used for assessment of single test values:

- Marshall stability: min. 6000N.
- Marshall flow: min. 2mm and max. 4mm.
- E-Modulus: min. 1600MPa
- Bitumen content: For Same-Himo 4.4%. Bitumen content falls in a range that gives 80-100kg/m$^3$ of bitumen in the compacted mix.

Measurements of voids in the mixes were unreliable due to difficulties in obtaining reliable test values for specific gravity of the absorbent natural gravel aggregates used on the projects. Studies of the test results however indicate that the void contents vary considerably more than for hot mixes and are generally in the order of at least 10% air voids. Newer methods offer a more reliable assessment of the absorption of fine material (Jenkins 2000), however projects in Tanzania cover an exceptionally broad variety of material qualities where even the coarse particles had excessive absorption.

The required stability of the bitumen foam was considered adequate when the ratio between the volume of the bitumen in a foamed state and in an un-foamed state was not less than 15 and in addition at least one of the following requirements were met:

1. the time from the foam is ejected into atmospheric pressure until the volume has decreased to half its maximum volume should be not less than 15 seconds, or....
2. the ratio between volume of bitumen in a foamed state and in an un-foamed state should be not less than 7.5 after 15 seconds have elapsed since the foam was ejected into atmospheric pressure.

Normal materials quality control in a full scale was applied on site, with regular testing of moisture content, aggregate grading, bitumen content, field density after compaction and Marshall values including indirect tensile strength tested on fresh material. Core samples were taken after the material had cured sufficiently to enable drilling of cores. This could take several months and such test results could therefore not form part of the acceptance control on site.

A list of other projects in Africa, where a similar technique has been used following the Same-Himo project is given in Appendix 1, where key material parameters are tabulated. The technology used on these projects was adopted in the Tanzania Pavement and Materials Design Manual-1999 on merit of these projects, subsequent pavement monitoring, and experience from elsewhere. There is however a possibility that the required properties of the foam itself as specified in the Tanzanian manual are difficult to meet using other foaming methods than those that were in use on the reference projects prior to the issue of the document.

5.2 Tanzanian material standards vs. the South African

The typical mix composition and material requirements given in the Tanzania Pavement and Materials Design Manual-1999 compared to those presented in the
South African Asphalt Academy are similar or close to similar with respect to grading and Atterberg Limits. The Asphalt Academy divides the mixes into ‘visco-elastic’ and ‘cemented’ types having respectively >2% bitumen and <2% bitumen, and describes the use of cement in the mixes. The Tanzanian manual does not describe the addition of cement in the mixes, and specifies a bitumen content of 80 to 100 kg/m$^3$ of compacted material, which translates into approximately 4.3% to 5.3% bitumen content depending on the density of the mixes. The Tanzanian manual specifies weight of bitumen per volume of mix because the traditional percentage of bitumen by weight is a measure that does not have general meaning seeing the considerable variation in density of mixes where a variety of qualities of natural gravel is utilised. In Tanzania there is experience of full scale construction using mixes with densities below 1600 kg/m$^3$ and above 2300 kg/m$^3$.

6 PAVEMENT MONITORING

6.1 Sections

The monitored sections presented in this paper have the following layout:

Section 1: km 372 + 200 to km 372 + 300.
100m long. Natural gravel premixed with foamed bitumen. Premixing technology was applied. In addition section km 371 to 372 were included for a reduced measurement programme.

Section 2: km 414+800 to km 414+900.
100m long. Natural gravel base course premixed with foamed bitumen. Imported materials were milled together with in situ existing pavement materials.

Section 3: km 428 + 500 to km 428 + 600.
100m long. Milled existing pavement. 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.

6.2 As-built data

6.2.1 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%.

6.2.2 Subgrade and subbase

Investigation and construction testing performed at different stages before and during construction indicated that the sub grade materials at all the three sections comprise of soils with the following nominal properties:

- CBR minimum 10% at 93% Mod AASHTO
- CBR swell maximum 1.5%
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\% (4 days soaked at 95% mod. AASHTO MDD)
- Average Field density = 96.7\% Mod AASHTO MDD
- OMC range = 5.6\% - 13.1\%

6.3 Monitoring programme

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

Rut depths were measured in wheel paths at identified locations at intervals of 10m. Measurements were done repeatedly at the same location every year.

Visual inspection was performed to cover the whole section in order to capture other deterioration indicators such as potholes, ravelling, cracks and bleeding.

6.3.2 Core sampling
Cores samples from the stabilised base course were taken at specific locations in accordance with a 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 a 100mm diameter were drilled from specific locations at 30 m intervals:

- Two cores from the LHS (heaviest trafficked) outer wheel track.
- Two cores from LHS (heaviest trafficked) between the outer and inner wheel tracks.
- One core from RHS (least trafficked) outer wheel track.

Efforts were made to protect the cores from drying out by the use of plastic bags. Given the possibility of drying out, partly offset by 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.

6.3.3 Laboratory tests
The cores taken from the stabilised base course were subjected to tests of:

- Indirect tensile strength (split testing), i.e. a compressive load across the diametric axis was applied to the cylindrical specimen. Specimens were conditioned in the oven at 29\(^\circ\)C for about 1hr before testing.
- Extraction and bitumen recovery tests in laboratory.

The recovered bitumen was subjected to tests of penetration, viscosity and softening point. These are indicative tests for ageing of bituminous binders.
PAVEMENT PERFORMANCE BY YEAR 2003/2004

Visual inspection
The visual inspection shows no development of potholes and no significant development of cracks, except for section at km 428 which has had a steady increasing crack development during the monitoring period. This may be caused by volumetric changes in the subgrade as this area is occasionally flooded.

Rutting
The result of rut measurements are shown in the Fig.7 as graphical presentations of the 90th percentile values in the outer wheel track.

![Fig. 7: Rut depth, Same-Himo](image)

Roughness
The surface roughness (IRI values) measured with MERLIN equipment are shown in Fig.8.

Deflection
Deflection (maximum) was measured only on section km 371 to km 372 (1 km long) adjacent to one of the monitored sections, the results are shown in Fig.9. The measurements were carried out in year 2000 by Benkelman Beam using the rebound method. Axle loading was 8100 kg and tyre pressure 590 kPa. Measurement frequency was 100m in outer and inner wheel track respectively.

![Fig. 8: Roughness, Same-Himo](image)  ![Fig. 9: Deflection, Same-Himo](image)
Measurements of E-Moduli

Fig. 10 shows the development of the E-Modulus of the base course through the monitoring period. The values were derived by measurements of indirect tensile strength of core samples in accordance with Norwegian practice that was prevailing at the time of construction. Each core sample was split into an upper and a lower sub-sample of respectively 0-60 and 60-120 mm depth below the surfacing.

Fig. 10: E-Modulus of the base course through the monitoring period

Bitumen properties

Properties of bitumen recovered from the stabilised base layer were tested in the laboratory for each of the monitoring sections. All tests were carried out in accordance with ASTM standard procedures. The test results for all three sections are shown in Fig.11.

Fig. 11: Properties of bitumen recovered from core samples
8 DISCUSSION OF THE RESULTS

8.1 General

By year 2000 the traffic loading in terms of E80 has reached just above 40% of the design traffic in the most heavily loaded lane (northbound). The design traffic loading of just under 5 millions E80s is expected to be reached as projected in 2005/6 at the end of the 15 years design period. The measured performance parameters do not show any difference between the lanes that can be related to axle loading except for rutting on one monitored section (km 414) where there are slightly higher values in the more trafficked lane. The magnitude of the rutting values are however so small that this part of the discussion has only academic value at this point in time.

8.2 Individual performance indicators

8.2.1 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.

8.2.2 Rutting

The rut depth measurements of all three sections show minor changes with time, the values are low, and the current pavement performance with regards to rutting is certainly very satisfactory.

A slightly higher initial rut depth of one section (km 414) is possibly caused by insufficient compaction and the effect of traffic soon after construction. Cold bituminous mixes made of foamed bitumen require a considerable compactive effort, and slight differences in site conditions - in particularly moisture content - may have the above result on the occasional section. Notably the section has not shown a greater increase in rut values during the time of service than the other sections.

There was a slight and gradual increase in rutting after the time of construction, from category ‘Sound’ approaching ‘Warning’ after 3 to 7 years in service, however a levelling out of the rut development has occurred since that time.

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. However, the values are indeed so low that inaccuracies during measurements on this type of surface are likely to give results that vary considerably in relative terms.

8.2.3 Roughness

Generally the roughness values for both the milled and cold premix sections are low. There has been no dramatic increase 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. One section is
barely approaching ‘Warning’, however this case is related to subsoil conditions rather than pavement distress.

8.2.4 Deflection
Deflection measurements have only been carried out once, in 2000, 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. Assessment of deflection against the criteria for a ‘lightly cemented basecourse’ is probably reasonable considering the hardening of the binder and the most likely structural behaviour of the basecourse.

8.2.5 E-modulus
The values for the E-Modulus of the base course were derived by measurements of indirect tensile strength of core samples through the monitoring period, in accordance with Norwegian practice that was prevailing at the time of construction. These values are not representative of the stiffness experienced in the pavement, but are likely to at least give an indication of the load distributing properties of the basecourse and possibly say something about the manner in which the material properties develop over time. It is noted that load distribution does not appear to have been critical for the performance of the pavement through the monitoring period.

There was a sharp increase in E-moduli of the bituminous basecourse during the first 3 years in service. Thereafter the values have declined, however to levels well above the design value of 1600 Mpa. 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.

The E-modulus was generally slightly higher in the upper part of the basecourse layer than the lower part of the layer (60-120mm). 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.

8.2.6 Binder hardening
The binder has hardened considerably since the time of construction and is gradually approaching a zero penetration value. Bitumen penetration was found to decline rapidly for all sections, and the values that are recorded at the last coring monitoring programme in 2003 are very low. Softening point and viscosity of the recovered bitumen was increasing with age against the decreasing penetration, as expected.

Hardening of the binder, from e.g. oxidation and evaporation processes, normally attack the bituminous materials on the exposed surfaces caused by high air-void content. The rate of hardening is also dependent on the binder film thickness in the materials, which may be very small in the case of foamed bitumen using aggregates with high fines contents. Foamed bitumen mixes typically have very thin bitumen film thickness due to finely distributed binder and a often large surface area on account of high fines contents. A combination of thin film thickness and high void contents is thereby likely to contribute to the rapid hardening of the bitumen in the stabilised base course at Same-Himo.
8.3 Summary of pavement condition by 2003/2004

Table 2 summarises the condition of the Same-Himo monitoring sections 13 years after construction in comparison to the criteria in the Tanzania Pavement and Materials Design Manual - 1999.

<table>
<thead>
<tr>
<th>Assessment, Same-Himo monitoring sections 2003/2004</th>
<th>*) Criteria for roads in traffic load class with &gt;3 million E80s</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Deflection (90%-ile, lightly cem)</strong></td>
<td>Sound: &lt;0.35 mm  Warning: 0.35 - 0.85 mm  Severe: &gt;0.85 mm</td>
</tr>
<tr>
<td>WARNING (Measured only once, after 10 years in service. Criteria for ‘lightly cemented’ base courses is used.)</td>
<td></td>
</tr>
<tr>
<td><strong>Roughness</strong></td>
<td>Sound: IRI &lt;3 m/km  Warning: IRI 3 - 6 m/km  Severe: IRI &gt;6 m/km</td>
</tr>
<tr>
<td>SOUND (One section barely approaching WARNING, however this case is related to subsoil conditions rather than pavement distress)</td>
<td></td>
</tr>
<tr>
<td><strong>Rutting (90%-ile)</strong></td>
<td>Sound: &lt; 5 mm  Warning: 5 - 15 mm  Severe: &gt;15 mm</td>
</tr>
<tr>
<td>SOUND/WARNING (Approached WARNING after 7 years since construction, but rut development has levelled out and there has been no increase since that time.)</td>
<td></td>
</tr>
<tr>
<td><strong>Cracking</strong></td>
<td>Sound: &lt; 10% (all cracks)  Warning: 10 - 30% (all cracks)  Severe: &gt;30% (all cracks)</td>
</tr>
<tr>
<td>SOUND (On individual sections WARNING to SEVERE, however this is related to subsoil conditions)</td>
<td></td>
</tr>
</tbody>
</table>


9 CONCLUSIONS

• The pavement on the Same-Himo road is near the end of its 15 years design period and has almost received a traffic loading of 5 million E80s that it was designed to withstand.
• The pavement has received no resealing or other periodic maintenance since construction.
• There has been no pothole development, but sealing of individual cracks has been undertaken on individual sections. There is no excessive development of rutting or surface roughness.
• The pavement is currently in an excellent condition.
• The pavement utilising natural gravel stabilised with foamed bitumen has performed very well throughout its design period on a heavily loaded trunk road in Tanzania.

10 ECONOMY

The technical methods described in this paper were used in full-scale construction and were selected on the basis of economical competitiveness. Cost savings compared to conventional methods can be considerable on projects where there is shortage of quarried stone, but suitable gravel sources are available nearby,
Alternatively existing pavement layers can be recycled. The following facts illustrate the present knowledge about cost competitiveness with reference to the Same-Himo project and others listed in Appendix 1:

- Studies of the construction costs on the Same-Himo pilot project indicates a construction cost saving in the range 20 - 25% compared to equivalent pavement alternatives (Overby 1996).
- The Himo-Arusha contract for pavement rehabilitation was awarded for the use of a conventional pavement type and a change to the alternative method using bituminous material was not acceptable unless the cost to the contract was similar or lower (Johansen 1997). The change of method took place in the manner that the contractor made a proposal that was evaluated by the consultant and accepted by the Government of Tanzania and the financing institution, African Development Bank. The process that lead to the change of pavement type gives a clear indication that the method is cost effective.
- All remaining projects listed in Appendix 1 had their pavement type selected on the basis of cost effectiveness and technical appropriateness assessed by the employer and the consultant.

11 REFERENCES


APPENDIX 1 - OVERVIEW OF PROJECTS UTILISING FOAMED BITUMEN IN TANZANIA AND ZAMBIA

<table>
<thead>
<tr>
<th>Country in Africa</th>
<th>Same-Himo pilot project</th>
<th>Tanzania</th>
<th>Zambia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>82 km</td>
<td>340 km</td>
<td>64 km</td>
</tr>
<tr>
<td>Type of project</td>
<td>Pavement rehabilitation</td>
<td>Emergency repairs</td>
<td>Pavement rehabilitation</td>
</tr>
<tr>
<td>Design traffic E80s</td>
<td>5 millions</td>
<td>-</td>
<td>1 million</td>
</tr>
<tr>
<td>Application of material stabilised with foamed bitumen</td>
<td>Base course 150-175mm, on some sections also used for subbase 100mm</td>
<td>Base course 150mm in patches and reconstructed sections</td>
<td>Base course 80-100mm</td>
</tr>
<tr>
<td>Placed material (tonnes)</td>
<td>250 000</td>
<td>70 000</td>
<td>350 000</td>
</tr>
<tr>
<td>Type of bitumen</td>
<td>80/100 pen</td>
<td>150/200 pen</td>
<td>80/100 pen</td>
</tr>
<tr>
<td>Nominal bitumen contents</td>
<td>4.4%</td>
<td>5.3%</td>
<td>4.7%</td>
</tr>
<tr>
<td>Construction</td>
<td>In-situ milling on half of the length, half using premix.</td>
<td>Premix using material from borrow pit: Stockpiled aggregate screened into two fractions (coarse/fine), subsequently combined in the mixer while adding bitumen and water. Laid with pavers.</td>
<td></td>
</tr>
<tr>
<td>Type of Aggregate</td>
<td>Weathered gneiss (natural gravel). - Milling of existing stabilised layers. - Material from borrow-pit.</td>
<td>Weathered gneiss (natural gravel) 0-35mm</td>
<td>Volcanic tuff (75%) mixed with (25%) fines from weathered gneiss (all being natural gravel), 0-25mm</td>
</tr>
<tr>
<td>Surfacing</td>
<td>Double surface dressing</td>
<td>Single surface dressing</td>
<td>Double surface dressing</td>
</tr>
<tr>
<td>Subbase</td>
<td>Natural gravel, CBR&gt;30</td>
<td>Natural, CBR&gt;45</td>
<td>Natural, CBR&gt;30</td>
</tr>
<tr>
<td>Climate, description in relative terms</td>
<td>Mainly dry, parts moderate</td>
<td>Mainly moderate, parts wet</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

All projects are in the tropics. The relative description of climate is based on the following:
- Wet climate has typically annual average rainfall more than 1200 mm.
- Moderate climate has typically annual average rainfall 500-1200 mm.
- Dry climate has typically annual average rainfall less than 500 mm.

<table>
<thead>
<tr>
<th>Finance</th>
<th>NORAD</th>
<th>Tanzania / NORAD</th>
<th>Tanzania / ADB</th>
<th>Zambia / NORAD</th>
<th>Zambia</th>
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</thead>
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