

FORENSIC STUDY INTO THE CAUSES OF PREMATURE FAILURES IN ASPHALT PAVEMENTS IN TANZANIA

J.K. Anochie-Boateng
CSIR Built Environment, Pretoria, South Africa
janochieboateng@csir.co.za

M.O. Mataka
TANROADS Central Materials Laboratory, Dar es Salaam, Tanzania
mussamataka@yahoo.co.uk

J.T. Malisa
TANROADS Central Materials Laboratory, Dar es Salaam, Tanzania
malisajt@yahoo.com

J.J. Komba
CSIR Built Environment, Pretoria, South Africa
jkomba@csir.co.za

ABSTRACT

Tanzania is faced with challenges of premature failures in roads and highways. Some asphalt pavements fail prematurely in less than five years of their expected 20 years design life cycle. These failures have been identified as mostly permanent deformation (rutting) in the asphalt concrete layers. The Tanzania National Roads Agency (TANROADS) and the Council for Scientific and Industrial Research (CSIR) have jointly initiated a collaborative study in premature failures in Tanzanian roads. The aim is to better understand the causes and mechanisms, which lead to these failures, with the primary objective of finding plausible solutions to the problem. This paper presents preliminary findings and outcomes of a forensic study into 12 road sections that have failed prematurely on a national highway referred to as the Tanzam highway. The methodology used in the study is discussed, and the conditions of the road sections as well as the observed rutting are presented. It was found that rutting on most of the road sections occurred in the outer wheel tracks. The minimum and maximum rut depths measured from the overlay rehabilitated road sections were 70 mm and 138 mm, respectively, which far exceed the acceptable rut depth of not more than 15 mm on Tanzanian roads. Remedial actions to be considered by TANROADS and practical recommendations to prevent future occurrences of similar incidences are presented.

1. INTRODUCTION

High incidence of premature failures in the form of permanent deformation (rutting) in asphalt concrete layers has been reported in Tanzania. This has been largely attributed to the recent increasing traffic volumes and loading on the highways, and roads in urban areas. Although overloading is a major concern, recent study by TANROADS has attributed the premature failures to the advent of wide base (“super single”) tyres on their roads (Report No.C22, 2014).

Rutting in asphalt concrete layers is one of the most frequent and more serious distresses associated with asphalt pavements (Dawley et al, 1990). Permanent deformation results in ponding of water in the wheel tracks which increases the potential for aquaplaning during wet weather. It also results in poor riding quality and increased vehicle-operating costs. Severe rutting condition is related to a situation that leads to unsafe driving conditions for the road user. One of the causes of accelerated rut development, especially when the

asphalt mat is still fresh, is insufficient compaction at the time of construction, which not only would result in higher levels of densification under traffic, but also could render the mix more susceptible to shear deformation in the early life of the asphalt concrete layer. Not achieving adequate levels of compaction will also result in higher degrees of permeability and binder hardening, which in turn, may lead to premature cracking, stripping and ravelling, shortening the life of the pavement. Additionally, if left untrafficked for an extended period, further densification may be significantly inhibited which will aggravate the onset of rutting. Verhaeghe et al (2009) reported that for every one per cent decrease in density below the minimum required density, the life of the asphalt layer could reduce by 10 percent.

The CSIR in collaboration with TANROADS is in the process of conducting a detailed investigation into the causes of premature failures in Tanzanian roads and highways. The goal is to identify the factors which contributed to the premature failures, and to identify an asphalt mix design methodology that is suitable for the prevailing environmental and traffic loading conditions. The Tanzam highway (T1) was selected for the study. T1 is historically known to experience the highest volume of heavy truck traffic in Tanzania.

2. PROJECT BACKGROUND

Studies previously conducted on roads in Dar es Salaam along T1 revealed that the failures were mainly permanent deformation in the form of rutting/shoving, bleeding and to a lesser extent, cracking in the bituminous layers. Causes of these failures were found to be mainly associated with the use of inappropriate materials and poor quality control during construction. Based on these findings, TANROADS initiated discussions with the CSIR, on how to effectively address the premature failures due to rutting in the asphalt concrete layers of roads and highways in Tanzania. Available reports have recommended the use of Superpave mix design method as the solution to the problem. The use of polymer modified binders has also been suggested by some consultants and contractors.

In July 2014, the CSIR was formally requested by TANROADS to conduct a detailed forensic investigation into the causes of premature failures in the asphalt concrete layers of a number of road sections in Tanzania. This investigation was regarded as a start of collaboration work between the CSIR and TANROADS for addressing the research and development's (R&D) needs of road building in Tanzania. The contract for the forensic study was signed in September 2014. This paper contains the preliminary outcomes and findings of work done thus far, on 12 road sections included in the study.

3. OBJECTIVES

The primary objective of the study was to conduct a detailed forensic investigation in the field and complemented with a laboratory test programme to determine the causes of premature failure of asphalt concrete layers on 12 road sections located on T1, and provide remedial measures as well as practical recommendations to prevent similar occurrences of the identified failures in the future. As part of the study, the quality of the asphalt mix design methodologies were to be assessed, and recommendations were to be made to TANROADS on the way forward to improve asphalt mix design and materials testing.

4. METHODOLOGY

The first task on the project was to conduct an inception study with an overall goal of (a) identifying possible causes of failure from available data (e.g. mix design and construction information), (b) assessing the quality of mix designs in broad terms and investigate whether or not, in retrospect, distresses on the road could have been avoided through appropriate asphalt mix designs, (c) identifying the differentiating characteristics of 'good' and 'poor' performing mixes, and (d) recommending sites that should be subjected to detailed forensic investigations. A "good" section is a road section that only requires routine maintenance to retain its present condition, whereas a "poor" section needs significant renewal or rehabilitation to improve its structural and/or functional integrity.

Based on the inception study, eight sections classified as "poor" and four sections classified as "good" were selected for a detailed assessment. The selection was mainly based on the discussions with TANROADS, and the available as-built data, material reports, performance data, climate data and traffic data, as well as the results of additional visual assessments performed during site visits.

The structural condition of all 12 road sections was assessed by means of non-destructive falling weight deflectometer (FWD) and dynamic cone penetrometer (DCP) tests. The primary objective of the FWD and DCP testing was to establish whether the behaviour of the poor performing sections was indeed related to asphalt concrete mix specific properties and not to the condition of the underlying layers.

After completion of the two tests, cored samples of the asphalt concrete layer were taken to determine their physical and engineering properties including density, stiffness, tensile strength, aggregate shape properties and grading. The condition of the binder recovered from the samples was assessed by means of various physio-chemical tests.

As part of the study, four main documents associated with asphalt mix design, and specifications in Tanzania were reviewed. These are: (1) Standard Specifications for Road Works (SSRW, 2000); (2) Pavement and Materials Design Manual (PMDM, 1999); (3) Laboratory Testing Manual (LTM, 2000); and (4) Field Testing Manual (FTM, 2003)..

5. PRELIMINARY SITE INVESTIGATION

The preliminary site investigation was conducted to select possible sites to be included in the detailed study. The objective was to:

- Develop a methodology that will facilitate the identification of the road sections to be included in the detailed forensic study;
- Consult all available data on selected road sections that failed prematurely, in an attempt to identify the root causes and the mechanisms of the failures, and to assess whether the occurrence of these distresses could have been prevented at the design stage given the current state of knowledge and the routinely-used design methods and tools in Tanzania;
- Identify good performing road sections and determine the reasons and factors that differentiate them from poor road sections (i.e. sections that exhibit premature failures);
- Determine the scope of the detailed forensic study to be undertaken on identified sections, based on outcomes of the preliminary investigation and consultation of the available data; and
- Prepare an inception report.

Limited coring of asphalt concrete samples and rut depth measurements were done. The following were general observations:

1. The predominant failure found on all road sections was rutting. In most cases, rutting was found to be a combination of densification (settlement) and severe shoving (heave /permanent shear displacement of the asphalt).
2. Other distresses observed in some sections, although minor, included bleeding/flushing and cracking. It was suspected that the type of cracking was reflection cracking which emanated from the stabilized base layers.
3. Road sections where the asphalt mix design was based on Marshall were found to be in a poorer condition when compared with sections designed with Superpave methodology. There is a general believe that Superpave mix design methodology will prolong the life of the asphalt pavement.
4. For some of the poor performing road sections that had been rehabilitated, the problems with the previous surfacing were reported as rutting. These ruts were believed to be worsened after the overlay rehabilitation by heavy truck traffic loading on the highway.
5. In some cases no good sections could be identified in a road length of 10 km. Also, a number of poor performing sections were observed on the opposing road lanes of most sites.
6. All road sections investigated appear to be constructed with medium and coarse densely graded asphalt concrete (AC14, AC20) with the coarse (AC20) being the predominant asphalt mix type used on T1.

The observations on rutting were in agreement with studies previously conducted on roads in Dar es Salaam and along the Coast and Iringa Regions on T1, which revealed the predominant failures as severe rutting. There are several possible causes that might have led to the rutting of the various road sections on T1 including poor asphalt mix designs and rehabilitation strategies, overloading, and high traffic volumes of very heavy trucks.

Based on the outcomes of the preliminary study, the following recommendations were made for the detailed study:

- The study should focus on T1, and one road section (Chalinze-Kitumbi) on the T2 highway. It was believed that T1 experiences the heaviest traffic loading conditions, and will be a good representation of roads and highways experiencing severe rutting in Tanzania. One site on the Nelson Mandela road in Dar es Salaam was recommended to be included in the study to represent urban roads that experience standing to slow transient traffic loading conditions.
- Visual inspection of the selected sites would be conducted in accordance with the CSIR protocol, complemented by the South African Standard Visual Assessment Manual for Flexible roads: Technical Methods for Highways series No. 9, TMH9 (1992). Visuals were to be conducted within 5 km of selected road sections.
- Detailed study to be conducted on 12 recommended road sections on T1. The selection was based on making sure that road sections included in the study cover different climates, asphalt mix design types, and different contractors / consultants.
- Based on a general consensus that asphalt mix design methodologies should include the Superpave concept and the use of polymer modified bitumens to manufacture asphalt for road construction, it was emphasized that Tanzanian asphalt design methodologies should be thoroughly reviewed.

- The asphalt mix design for the selected good performing sections (except one) should be based on Superpave methodology. It was anticipated that the information obtained from these sections will assist in making decisions on whether or not the same designs should be adopted or whether an improved design method is required for Tanzania.
- There was a need to include one good section based on the Marshall mix design to evaluate the base asphalt layer which was found to be dense bitumen macadam.
- Traffic data for the road sections to be included in the study should either be obtained from regional pavement management systems (PMS) or a new traffic data need to be assessed by TANROADS.

The detailed results of the preliminary investigation are contained in the inception report of the project (CSIR/BE/TIE/ER/2014/0066/C, 2014).

6. FIELD STUDY, DATA COLLECTION AND ANALYSES

6.1. Selection of road sections

The CSIR project team in partnership with the TANROADS project team conducted the detailed field investigation of six sites, representative of 11 road sections on the Tanzam highway (T1), and one section on T2 highway. The length and position of the road sections selected for the investigation were based on the extent of rutting and uniformity. Where possible, one “good” section and one “poor” section were investigated for each site. Relatively moderate rut sections were generally selected for the detailed investigation. Within the 5 km of each section, a road length of 100 m was earmarked to collect samples for a detailed study. All sections were selected in the one lane westbound direction of T1. Table 1 provides information of the selected road sections included in the study.

Table 1: Road Sections Included in the Study.

Section	Chainage	Climatic /Moisture	Name of Road	Section Condition	Distress Type	Test Pit
1	1+900	Moderate	Nelson Mandela	Good	-	No
2	8+000	Moderate	Nelson Mandela	Poor	Rutting	No
3	65 ¹ (2+150)	Moderate	Mlandizi-Chalinze	Poor	Rutting	Yes
4	0 ² (51+800)	Moderate	Chalinze-Kitumbi	Poor	Rutting	No
5	99+000	Moderate	Chalinze-Morogoro	Poor	Rutting	No
6	103+500	Moderate	Chalinze-Morogoro	Good	-	No
7	333+350	Moderate	Mikumi-Iyovi	Poor	Rutting	Yes
8	394+850	Moderate	Iyovi-Iringa	Good	-	No
9	495+615	Moderate	Iyovi-Iringa	Poor	Bleeding	No
10	546+015	Moderate	Iringa-Mafinga	Good	-	No
11	547+316	Moderate	Iringa-Mafinga	Poor	Rutting, cracking	Yes
12	849+000	Wet	Makambako-Mbeya	Poor	Rutting	Yes

¹:65 km from Dar es Salaam; ²: reference on T1 at Chalinze;

6.2. Visual inspection

The degree and extent of visible distresses were recorded and evaluated in accordance with guidelines as set out in TMH 9 (1992). Figure 1 presents the degree of rutting and bleeding. The degree of zero (0) means no distress, whereas five (5) indicates a severe distress condition. There were apparently no distresses observed on the good sections of Iyovi-Iringa and Iringa-Mafinga. These results are incomplete as the visual inspection results of Nelson Mandela and Chalinze-Kitumbi sections were not available for reporting. Of significance is the fact that the three overlay rehabilitated road sections (Mlandizi-Chalinze, Mikumi-Iyovi and Makambako-Mbeya) showed more severe rutting and bleeding

than all other sections. Severe shoving was also associated with the rutting observed in these sections.

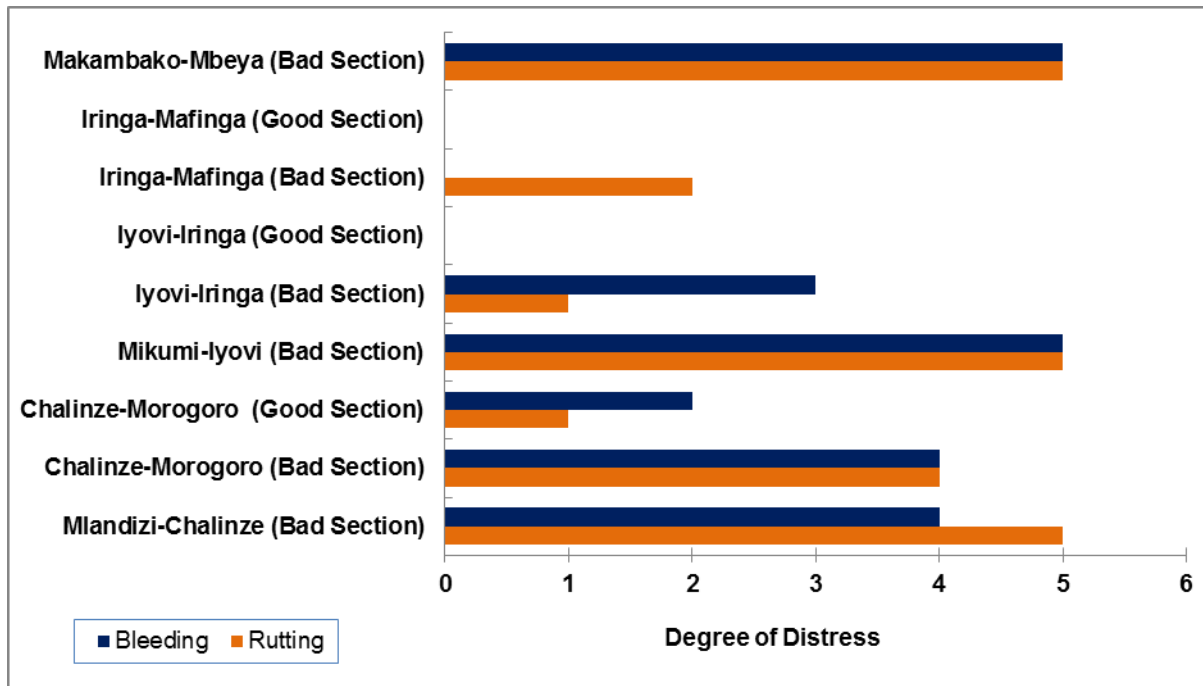


Figure 1: Observed critical distresses for nine road sections –TMH 9 criteria

6.3. Rut depth measurement

A two-meter long straight edge and a wedge were used to measure rut depths of the road sections on the Tanzam highway in accordance with procedures set in TMH 9 (1992). Rut depth is defined as the maximum permanent deformation measured under the two-meter straight edge. The cross sectional profile was measured from the yellow line on the shoulder towards the centre of the road. In most cases, the cross sectional profile was measured by placing the straight edge on top of the shoved asphalt concrete so that a measurement of zero (0) mm could be obtained on the shoulder.

Figure 2 and Figure 3 show the maximum rut depth for the outer and inner wheel tracks, respectively. It is important to note that the rut depths presented in these graphs are the total rut depth for both densification and shoving. Generally, the measurements for the outer wheel tracks were found to be higher than those of the inner wheel tracks.

Distances far away from coring positions experienced more rutting than those close to the sections where the cores were extracted. This was the objective of sampling for the study, i.e. samples for detailed study were to be taken at moderately failed road sections within 5km.

These results are in agreement with the visual condition assessment results presented in Figure 1, which shows that Mlandizi-Chalinze, Chalinze-Morogoro, Mikumi-Iyovi and Makambako-Mbeya road sections have experienced severe rutting when compared with the other road sections. The rut depths measured on the Nelson Mandela road section also indicate a severe condition of rutting.

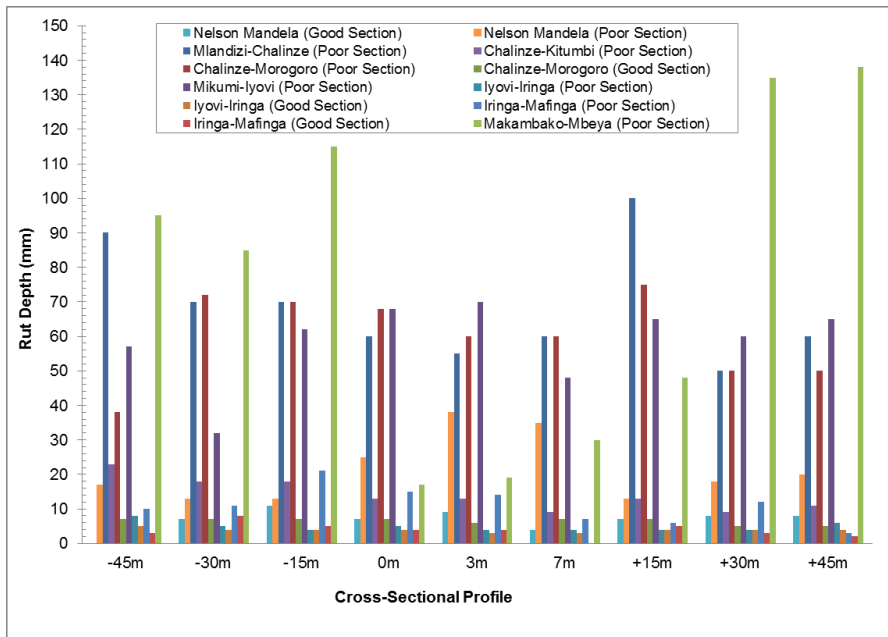


Figure 2: Maximum rut depth for outer wheel track

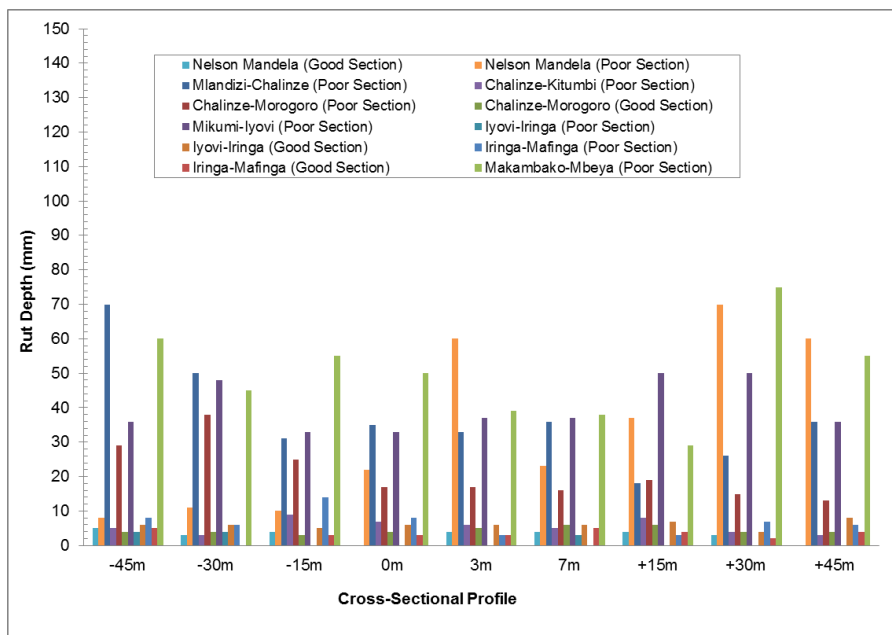


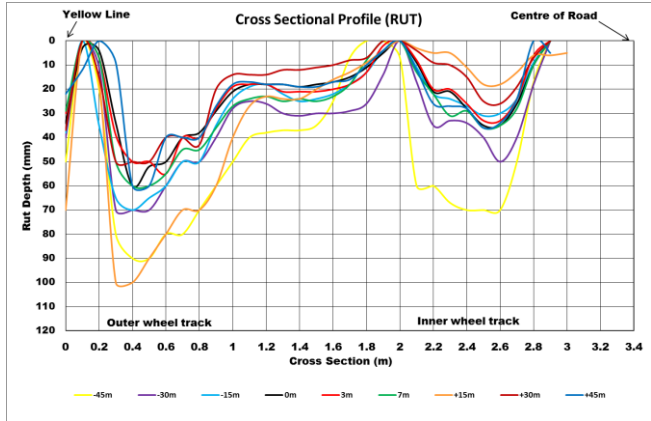
Figure 3: Maximum rut depth for inner wheel track

6.4. Detailed rut depth results for four road sections

Figure 4 shows detailed results of rut depth measurements for the Mlandizi-Chalinze, Chalinze-Morogoro, Mikumi-Iyovi, and Makambako-Mbeya road sections. A common feature for these sections was that after rain, water stays in the wheel tracks, resulting in ponding and aquaplaning. In addition, bleeding was accompanying rutting on some sections. The maximum rut depth in the outer wheel track was about 140 mm, and the maximum rut depth in the inner wheel track was about 70 mm. Figure 5 shows test pits indicating that rutting on the Mlandizi-Chalinze, Mikumi-Iyovi, and Makambako-Mbeya road sections was restricted to the asphalt layers of the pavement whereas rutting on the Iringa-Mafinga road section can be attributed to both underlying and the asphalt concrete layers.



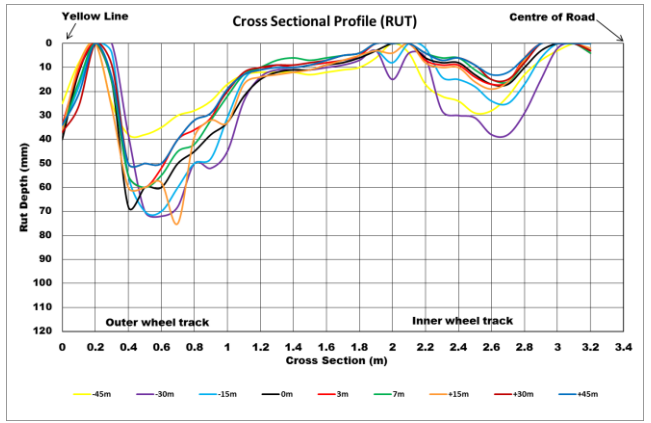
(a) Severe rutting on Mlandizi-Chalinze road section



(b) Ruth depth along cross section of Mlandizi-Chalinze road



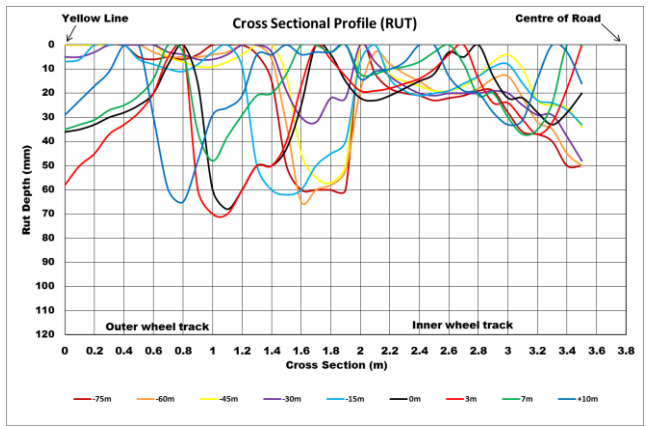
(c) Rutting on Chalinze-Morogoro road section



(d) Ruth depth along cross section of Chalinze-Morogoro road



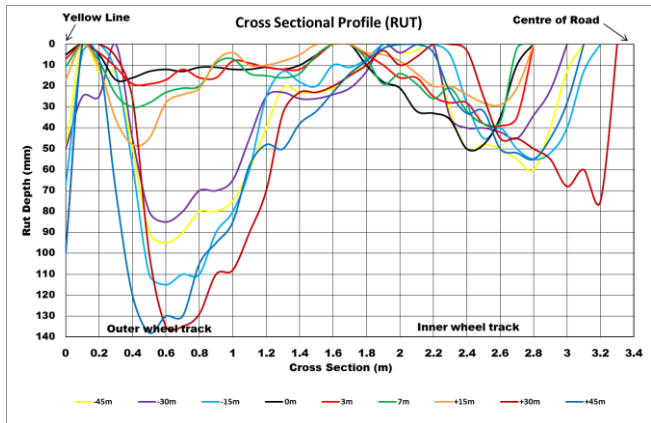
(e) Rutting on Mikumi-Iyovi road section



(f) Ruth depth along cross section of Mikumi-Iyovi road



(g) Rutting on Makambako-Mbeya road section



(h) Ruth depth along cross section of Makambako-Mbeya road

Figure 4: Condition of road sections and rut depth results.



(a) Test pit at Mlandizi-Chalinze road section



(b) Test pit at Iringa-Mafinga road section



(c) Test pit at Mikumi-Iyovi road section



(d) Test pit at Makambako-Mbeya road section

Figure 5: Photographs of open test pits for the four road section.

6.5. Asphalt materials coring

Core samples have traditionally been used to determine layer thickness, and tested in the laboratory to determine the physio-chemical and engineering properties of the component materials, and the samples. 100-mm and 150-mm diameter cores were extracted from the road sections for detailed visual assessment and laboratory evaluation of the binder, aggregates and asphalt mix properties. The samples were extracted in the left wheel track, between wheel tracks and the right wheel track of the westbound lane of T1. All cores were assessed to determine the extent of damage to the asphalt surface layers, i.e. width and depth of cracking, *porosity*, segregation, binder condition, bleeding and other conditions.

Coring at the rehabilitated road sections showed that during rehabilitation, the old asphalt layers were not milled out before new overlays were placed. Thus, the core samples extracted consist of the new and old surfacing layers.

Figure 6 shows the layout of typical coring positions and locations for each road section. At each section, a total of 24 asphalt cores were extracted in the areas exhibiting moderate rutting, out of which eight cores from each site were taken in the outer left wheel tracks, between wheel tracks and in the right wheel tracks. A total of eight cores were retained for replacement of damage cores and repeats of laboratory tests which provide doubtful results. All sampling/coring positions were maintained at the specified intervals of 1m.

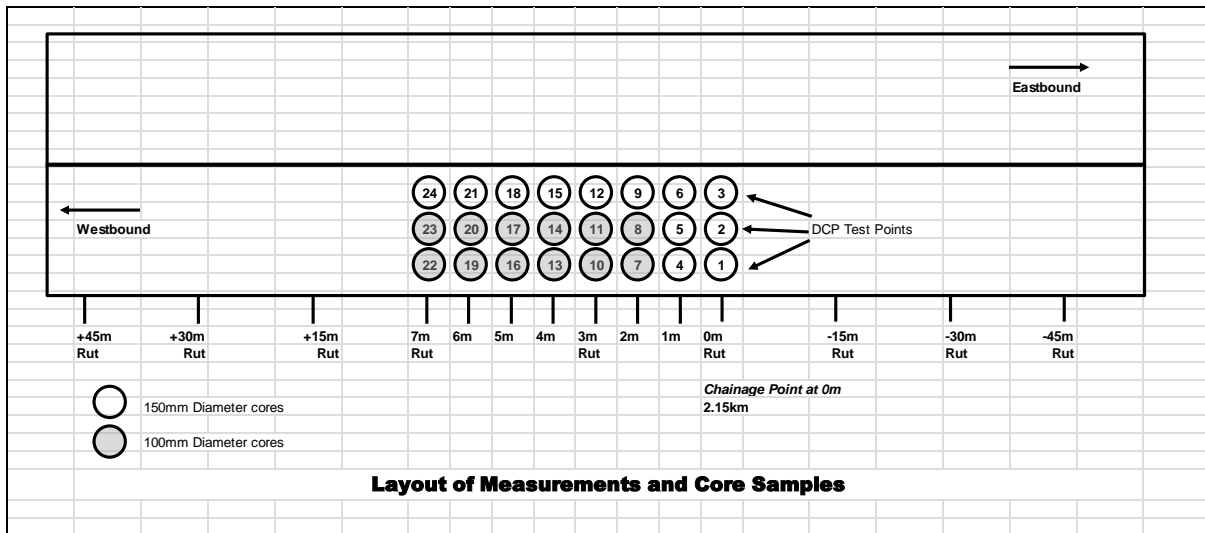


Figure 6: Typical Layout of Road Section used during this Investigation.



(a) Core position and holes for a road section



(b) DCP tests at core positions



(c) Core from Makambako-Mbeya road overlay road section



(d) Core from Mlandizi-Chalinze overlay road section

Figure 7: Field coring and core samples from road sections

7. FINDINGS AND DISCUSSION OF RESULTS

In Tanzania, the 90th percentile value of the rut depth per section should be reported. The distress criteria for rutting are based on traffic classifications. For traffic class of less than 1 million Equivalent Single Axle Loads (ESALs), the 90th percentile rut depth of more than 20 mm is considered severe. On the other hand, for traffic class of 3 million ESALs, or higher, the 90th percentile rut depth of more than 15 mm is considered severe (CML FTM, 2003).

The 90th percentile of maximum rut depths ranges between 5 mm and 138 mm for the measurements taken in the outer wheel tracks, and ranges between 4 mm and 70 mm for the inner wheel track measurements. For the rehabilitated sections the 90th percentile minimum and maximum values were 70 mm and 138 mm, respectively, with the outer wheel track recording the maximum rut depths for all road sections. Accordingly, rutting on T1 (> 40 million ESALs), is considered severe as the 90th percentile value for the sections investigated far exceeded 15 mm.

The rutting on the road sections is so severe that, to some extent, they were impassable or only allow very slow and uncomfortable movement that does not support the functions of the highway. Drivers avoid the defect by selecting a different path and drive very slowly. It has become difficult for overtaking and manoeuvring across deep rutting, and small cars are at high risk of by hitting shoved asphalt concrete, thus making users vulnerable to accidents.

The main findings from the field investigation are as follows:

- Most sections exhibited severe rutting with associated shoving, especially the rehabilitated sites of Nelson Mandela, Mlandinzi-Chalinze, Chalinze-Morogoro, and Makambako-Mbeya. The Iyovi-Iringa poor section also exhibited moderate to severe bleeding. Few sections showed cracking (e.g. Chalinze-Kitumbi, Mlandinzi-Chalinze). Other distresses observed in some sections include bleeding / flushing.
- The nominal rut depth measured along the poor road sections (minimum 70 mm and maximum 140 mm) far exceeded the most severe conditions in accordance with Tanzanian standards.
- The average maximum pavement temperature of the road sections in the period of 10 years ranges between 51°C and 57°C. If not taken into account, such high pavement temperatures could lead to a poor asphalt mix design under high traffic loading conditions if the wrong type of binder and aggregate skeleton is specified.
- The maximum ruts occurred in the recently rehabilitated sections with asphalt overlays. Asphalt overlays are the most common rehabilitation strategy to restore both functional and structural capacity of a pavement. However, it is not uncommon for an asphalt overlay to perform poorly due to continued rutting of the old asphalt layer underneath the new asphalt layer. It was established that during the overlay rehabilitation of some of the road sections investigated, there was no milling out of the existing rutting surfacing before the overlay asphalt was placed.
- Test pit profiling results indicated that most rutting experienced in the road sections can be attributed to the asphalt layers. Contributions of underlying layers to rutting were limited in one road section (i.e. Iringa-Mafinga).
- The field study concluded that the majority of the road sections on T1 are in a dire need of rehabilitation.
- The DCP and FWD data indicated sufficient structural strength in the underlying pavement layers on the majority of the road sections, implying that rutting in the road sections investigated was mostly confined to the asphalt layers.

8. LIKELY CAUSES OF PREMATURE FAILURE AND REMEDIAL ACTIONS

Rutting is a common distress observed in flexible pavements caused by the development of permanent deformation in layers of the pavement structure. Ruts usually occur in the wheel tracks as a result of traffic loads. The development of permanent deformation in asphalt layers has generally been described as a two stage process. The first stage consists of densification (volume change) under traffic after initial compaction during construction, while the second stage consists of shear deformation (plastic flow). In extreme cases such as observed on some road sections investigated on T1, densification and shear deformation have occurred concurrently leading to severe rutting in the asphalt layer.

Densification may produce significant rutting in thick asphalt layers (e.g. new or overlay rehabilitated sections), and which are compacted during construction to air void contents considerably higher than the long-term air void contents for which the mixes were designed. Shear deformation or plastic flow is the lateral movement of the mix away from the wheel tracks, most often as a result of excessive binder content, aggravated by use of excessive fines, improper aggregate grading, rounded aggregates and/or inadequate compaction during construction. This situation occurred on the majority of the road sections included in this study and on the Tanzam highway as a whole.

Premature rutting that develops unusually rapidly and reaches a critical level within a year or two, occurs sometimes due to poor asphalt mix design resulting in shear failure. The most common cause of this failure is associated with routes with heavy loads and high tyre pressures.

A more detailed discussion and practical consideration based on the information and data obtained thus far from the study are highlighted. A summary of the identified cause and mechanism of distresses observed on the poor road sections included in this study, and preliminary remedial measures (rehabilitation options) are presented.

Based on the perceived likely causes of the distresses observed in poor performing road sections, various applicable rehabilitation options were identified for remedial action. The rehabilitation strategy used for all four poor road sections included in this paper was an asphalt overlay. For these road sections, it was established that at least part of the observed problems were caused by possibly incorrect rehabilitation options. A typical solution is to mill out the rutted layer, and replace the failed layer with a new high stability asphalt mix, especially where the sub-structure is sound.

Table 2 presents the options to be considered for the various road sections. The proposed options are the immediate rehabilitation remedial actions which are applicable to similar poor sections along the Tanzam highway.

Table 2: Recommended Rehabilitation Option for the Investigated 'Poor' Sections on T1

Name of Road section	Condition of Section	Critical Distress	Cause and Mechanism	Rehabilitation Option
Mlandizi-Chalinze	Poor, rehabilitated road section	Rutting/shoving	Unstable asphalt mix (poor mix design) for the heavy truck traffic and axle loads on T1. Occurred over long sections in this road possibly due to high axle loads (from heavy trucks) causing densification, or shear failure (plastic flow) in the asphalt layers.	Overlay, mill out and replace (full depth-asphalt, full lane width) the unstable mix with a high stability mix (> 100 mm asphalt binder/base course, 40 mm - 50 mm wearing course). Use strong stone skeleton mixes (e.g. Dense graded mixes) with or without modified binders for wearing course, and a high stiffness mixes (with or without modified binder, EVA, SBS) for base/binder course. Use high quality, angular and rough textured crushed stones in the mix.
Chalinze-Morogoro	Poor, rehabilitated road section	Rutting/shoving	Unstable asphalt mix (poor mix design) for the heavy truck traffic and axle loads on T1. Occurred over long sections in this road possibly due to high axle loads (from heavy trucks) causing densification, or shear failure (plastic flow) in the asphalt layers.	Overlay, mill out and replace (full depth-asphalt, full lane width) the unstable mix with a high stability mix (> 100 mm asphalt binder/base course, 40 mm - 50 mm wearing course). Use strong stone skeleton mixes (e.g. Dense graded mixes) with or without modified binders for wearing course, and a high stiffness mixes (with or without modified binder, EVA, SBS) for base/binder course. Use high quality, angular and rough textured crushed stones in the mix.
Mikumi-Iyovi	Poor	Rutting/shoving and bleeding.	<u>Rutting</u> : Unstable asphalt mix (poor mix design) for the heavy truck traffic and axle loads on T1. Occurred over long sections in this road possibly due to high axle loads (from heavy trucks) causing densification, or shear failure (plastic flow) in the asphalt layers. <u>Bleeding</u> : Consequence of poor mix design (bitumen content in excess of that which the air voids in the asphalt mix can accommodate usually at high temperatures. Bitumen migrates to the surface of the pavement.	Overlay, mill out and replace (full depth-asphalt, full lane width) the unstable mix with a high stability mix (> 100 mm asphalt binder/base course, 40 mm - 50 mm wearing course). Use strong stone skeleton mixes (e.g. Dense graded mixes) with or without modified binders for wearing course, and a high stiffness mixes (with or without modified binder, EVA, SBS) for base/binder course. Use high quality, angular and rough textured crushed stones in the mix. Both rutting and bleeding can be addressed by the options provided.
Makambako-Mbeya	Poor, rehabilitated road section	Rutting/shoving	Unstable asphalt mix (poor mix design) for the heavy truck traffic and axle loads on T1. Occurred over long sections in this road possibly due to high axle loads (from heavy trucks) causing densification, or shear failure (plastic flow) in the asphalt layers.	Overlay, mill out and replace (full depth-asphalt, full lane width) the unstable mix with a high stability mix (> 100 mm asphalt binder/base course, 40 mm - 50 mm wearing course). Use strong stone skeleton mixes (e.g. Dense graded mixes) with or without modified binders for wearing course, and a high stiffness mixes (with or without modified binder, EVA, SBS) for base/binder course. Use high quality, angular and rough textured crushed stones in the mix.

9. CONCLUSIONS AND RECOMMENDATIONS

The following preliminary conclusions are based on information and data gathered thus far:

- The degree and extent of rutting on T1 are at unacceptable conditions requiring immediate interventions. It is believed that the possible (probable) causes are mainly due to asphalt mix designs which do not cater for high traffic volumes and loading, as well as high pavement temperatures.
- The cause of the severe rutting in the overlays on the rehabilitated road sections is attributed to poor asphalt mix selection.
- With increasing traffic volumes, heavy loading, and elevated temperatures on the Tanzam highway, it is clear that the empirical Marshall mix design procedures are sufficiently reliable in addressing asphalt mix design in Tanzania.
- The perception of the road designers and industry that the Superpave mix design methodology will prolong the life of the asphalt mix has not yet been proven conclusively in this study, as bleeding was observed on the Iringa-Mafinga road section (Superpave design). However, the road sections where the asphalt design was based on Marshall exhibited severe failures than Superpave.
- Asphalt surfacing on T1 is generally subjected to high traffic volumes and loading and elevated temperatures, under which the binder softens significantly. For such conditions, especially where resistance to rutting is the key consideration, the preferred mixes are, coarse dense-graded asphalt, with strong aggregate skeleton, and modified binders.
- Several sections on T1 are in a dire need of rehabilitation in order to be responsive to the safety and socioeconomic needs of the country.

The following preliminary recommendations are made based on the study:

1. An interim asphalt mix design guideline that provides step-by-step procedures for the selection of mix components should be developed as a matter of urgency to address mix design issues. Based on this a substantive asphalt mix design manual can be developed for Tanzania.
2. With high volumes of very heavy loading traffic on Tanzanian roads and highways, the use of rut-resistance asphalt mixes such as coarse dense-graded mixes with strong aggregate skeleton should be promoted in Tanzania.
3. In view of the apparent incorrect rehabilitation strategies that were adopted for some of the sections investigated, it is strongly recommended that a sound rehabilitation and good construction practices be adopted as a matter of urgency.

ACKNOWLEDGEMENTS

This paper was prepared under the cooperation between Transport Infrastructure Engineering Group of CSIR Built Environment and Central Materials Laboratory (CML) of Tanzania National Roads Agency (TANROADS - sponsor of the project). The authors wish to acknowledge Eng Patrick Mfugale, the Chief Executive of TANROADS for his interest in the project, and valuable suggestions throughout the course of this study. The project team members from TANROADS include Eng Jasson Rwiza, Director of Planning, Eng Chrispianus Ako, Director of Projects, Eng Julius Ndyamukama, Regional Manager, Dar es Salaam, Eng Paul Lyakurwa, Regional Manager, Mbeya, and Mr Belington Mariki, CML. The team members from CSIR include Mr Benoit Verhaeghe, Mr Colin Fisher, Mr. Johan O'Connell, Mr Georges Mturi, Dr Morris de Beer, and Dr Martin Mgangira.

REFERENCES

1. Anochie-Boateng, JK. 2014. A Study on the Causes of Premature Failures of Road Bituminous Layers in Tanzania and Review of the Tanzanian Asphalt Mix Design Methods, CSIR Inception Report CSIR/BE/TIE/ER/2014/0066/C, Pretoria, South Africa.
2. Central Materials Laboratory (CML). Investigation of Failures along Mlandizi-Chalinze Road (44 km). Report No. C221, Dar es Salaam, Tanzania, November 2014.
3. Dawley, C. B., B. L. Hogewiede, and K. O. Anderson, "Mitigation of Instability Rutting of Asphalt Concrete Pavements in Lethbridge, Alberta, Canada," Journal of the Association of Asphalt Paving Technologists, Vol. 59, Association of Asphalt Paving Technologists, St. Paul, Minnesota, 1990.
4. The United Republic of Tanzania Ministry of Works. Field Testing Manual. Dar es Salaam; 2003; (FTM).
5. The United Republic of Tanzania Ministry of Works. Laboratory Testing Manual. Dar es Salaam; 2000; (LTM).
6. The United Republic of Tanzania Ministry of Works. Pavement and Materials Design Manual. Dar es Salaam; 1999; (PMDM).
7. The United Republic of Tanzania Ministry of Works. Standard Specifications for Road Works. Dar es Salaam; 2000; (SSRW).
8. TMH9. 1992. Pavement Management Systems: Standard Visual Assessment Manual for Flexible Pavements. Technical Methods for Highways. South Africa Department of Transport, Pretoria, South Africa.
9. Verhaeghe, B. M. J. A., Myburgh, P.A., and Denneman, E. (2009). Asphalt rutting and its Prevention. The 9th Conference on Asphalt Pavements for Southern Africa. 2–5 September 2007, Gaborone International Conference Centre, Grand Palm Hotel & Casino Resort, Gaborone, Botswana.