COLLEGE OF SCIENCE AND TECHNOLOGY

FACULTY OF ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING AND ENVIRONMENTAL TECHNOLOGY

MASTER OF SCIENCE IN TRANSPORTATION ENGINEERING AND ECONOMICS

A THESIS ON

EVALUATION OF DAMAGE CAUSED TO ROAD STRUCTURAL PAVEMENTS BY UTILITY SERVICE PROVIDERS

A CASE STUDY OF KIGALI CITY

To be submitted in partial fulfillment of the requirements for the award of

MASTER OF SCIENCE IN TRANSPORTATION ENGINEERING AND ECONOMICS (TEE)

Submitted by:

Eng. Clay BONISHULI

Reg. N^{o}: PG 2011562

Under the Guidance of:

Associate Professor Jennaro ODOKI

JULY, 2014

DECLARATION

I **BONISHULI Clay** personally initiated this study with interest to evaluate the distresses, which are inflicted by utility cuts on road structural pavements in Rwanda. This study has never been carried out or submitted for award of a master degree in any university or institution of higher learning.

Signature……………………………………… Date 30th July 2014

BONISHULI Clay

This dissertation has been submitted in partial fulfilment of the requirements for award of the Degree of Master of Transportation Engineering and Economics (TEE) of College of Science and Technology, University of Rwanda with approval of the Supervisor.

Signature……………………………………… Date: 30th July 2014

Associate Professor Jennaro ODOKI

ACKNOWLEDGEMNTS

I am indeed grateful to my Supervisor Dr. Jennaro ODOKI without his tireless effort, timely guidance, inspiration, advice and knowledge imparted throughout the exercise this research would not have come to fruition.

My heartfelt gratitude is highly indebted to my beloved friends, course mates for their good ideas, comments and discussions exhibited towards making this study a success.

Special thanks are advanced to my Wife INGABIRE Albertine, my childrenUMWALI Tracy Laurianne, NYEMAZI Brian, KAYITESI AnithaLannah and GANZA Kennan Bliss, my Parents BONISHULI Evariste and MUKANYEMAZI Benedicte, my brothers and sisters and my Uncle, for their enormous sacrifice to enable me attain this master degree.

Furthermore, I wish to acknowledge the staff and management of National Bank of Rwanda, City of Kigali, utility companies, and the road sector for material support, cooperation and cordial relationship during this research.

I also wish to than the administration, staff and management of college of science and technology, university of Rwanda, specifically Faculty of Technology for the effective coordination, encouragement and moral support. Your parental approach to pressing students' issues perseverance and tolerance inspired me a lot.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AASHTO	American Association of State Highways and Transportation Officials
BS	British Standards
CEM I	Portland cement US 310-1
CBR	California Bearing Ratio
CoK	City of Kigali
CHOGM	Commonwealth Heads of Government Meeting
DD	Dry Density
DCP	Dynamic Cone Penetrometer
ESA	Equivalent Standard Axles
EWSA	Rwanda Energy Water and Sanitation Limited
ICT	Information and Communication Technology
MC	Moisture Content
MDD	Maximum Dry Density
MININFRA	Ministry of Infrastructure - Rwanda
MOWHC	Uganda Ministry of Works Housing and Communication
MOTC	Kenya Ministry of Transport and Communication
MTN	Mobile Telecommunication Network
OMC	Optimum Moisture Content
OPC	Ordinary Portland cement
RDB	Rwanda Development Board
RTDA	Rwanda Transportation Development Agency
SAQ	Structured Administered Questionnaire

ABSTRACT

This research concerns an evaluation into the damage caused to road structural pavements by service providers in Rwanda. Majority of utility service provider’s infrastructure lies underground, often partly or wholly beneath road pavements. Kigali road structural pavements are getting dilapidated by the activities of utility service providers through cuts not repaired in time, and those repaired failing prematurely despite provision of specifications to contractors. The study aimed at assessing road surface damage (cracks, depressions, potholes and bleeding) caused by utility cutting and their progressions overtime. The objectives were to evaluate the practices of contractors when selecting materials for repair of utility cuts and compacting pavements layers, establish the resultant effects of repaired cut distresses and recommend best practices to reduce repaired cut distresses on road pavements.

The methodology used comprised of literature review, questionnaire survey to technical staff of utility companies (telecommunication, electricity, water & sanitation), contractors and road authorities. Forms of distresses on repaired utility cuts were visually identified, monitored, measured and recorded on observation sheets. Their variations over three month period were monitored. Field tests (using Dynamic Cone Penetrometer – DCP) were carried out to establish soil structural strength and properties on repaired utility cuts and a sand replacement method was used for moisture content test. For laboratory tests, soil samples were subjected to British Standards heavy compaction test to establish the degree of compaction. The resultant effects like road service life, distresses on five roads were identified and observed.

The study showed road surface damage (distresses) in form of cracks, bleeding, depressions and potholes and their progression overtime. Contractors flout set standards during selection of materials and compacting pavement layers during repair of utility cuts. The effects of utility cut distresses were reduction in road service life and serviceability, increased maintenance costs and unnecessary traffic jams. The recommendations were involvement of utility service companies at all stages of road construction projects, best remedial measures as trenchless technology, core boring and design based on sound engineering fundamentals. Area of further research, evaluation of impact of road drainage on the utility workability was proposed.

CHAPTER ONE: INTRODUCTION

1.1 Background

Rwanda is challenged by the global rapid urbanization like most developing countries. According to the World Bank, Rwanda's growth performance has been remarkably strong over the past two years. Real growth accelerated to about 7.2% in 2010 and 8.6% in 2011 from 4.1% in 2009 *(Rwanda Strategic Transport Master Plan – Final Report September 2012)*. In 2000, the level of urbanization was 16.1% with urban growth rate of 5.5%. The trend is influenced by social economic opportunities in urban areas. The NSIR estimated the Kigali population at 703,000 in 2007. However, Kigali City is coupled with increased demand for utility services provision such as water and sewerage, telecommunication, internet and electricity to serve the surging population. Majority of utility service provider's infrastructures lies partly or wholly underneath road structural pavements. This has created an infringement on road structural pavement during and after repair cuts. Road structural pavements constitute a durable structural materials laid down on an area intended to sustain vehicular or pedestrian traffic/loads. In the past cobblestones and granite sets were extensively used, but these surfaces have mostly been replaced by asphalt. Such surfaces are frequently marked to guide traffic. Today, permeable paving methods are beginning to be used for low-impact roadways and walkways *(Merriam-Webster online dictionary, 2008)*. A road pavement is the actual structure on which the vehicles travel. Its main purpose is twofold, to provide friction for the vehicles and to transfer and reduce traffic load to the underlying soils *(Croney, 1972)*. Road transport is by far the most dominant mode of transport in Rwanda, carrying over 90% of passenger and freight traffic. The national roads currently make up almost 20% of the road network but carry over 85% of the total road traffic. They also provide vital transport corridors to the neighbouring land locked countries of Burundi and Republic of Democratic Congo (Eastern and Southern parts).

Walaa and Elhussein (1999) observe that every day a substantial number of utility cuts are dug and restored in every City worldwide either to install new services or to repair and upgrade existing facilities. It is observed that though utility cuts are normally restored based on specific design and construction practices, they continue to perform poorly in many cases. In addition to the above, Walaa and Elhussein (1999) studied the restoration practices and found out that by then, Contractors had neither a mechanism to evaluate the impact of digging and removing soil nor design or construction specifications to reduce the attendant effects. It is further indicated that absence of a sufficient engineering practice is the main cause of restoration problems.

Trevor et a.l, (2006) advance that one of the main inefficiencies associated with the current practice is lack of coordination between the various utility service providers that need to access pipes and lines running underneath roads. It is also argued that changes from classical cut, open and restore to trenchless technology of utility installation might see reductions in compliances costs. This will be through initiatives such as the introduction of National standards, reduced costs for local Government through less damage to roads and drains, and benefits to communities through fewer road accidents. It is recommended that utility Companies operating in the public right of way should coordinate between themselves and Rwanda Transport Development Agency (RTDA) to ensure responsible utilization of public resources by parties involved. Jones (1999) observed an increasing need by utility service providers to “access” the underground facilities for maintenance and rehabilitation of aging cities and utility systems, which in turn creates serious financial stress on Cities and utility Companies alike. Ministry of works, housing and communications - Uganda [MOWHC] in 2005 points out that repetitive digging of roads results into traffic delays and damage to road surfaces and cause frustration for motorists and road operators. It was observed that observed that damage to road infrastructure in Rwanda is partly inflicted by utility services providers namely; Energy, Water and Sanitation Authority (EWSA), Rwanda Development Board (RDB) and telecommunication Companies. However, studies above do not provide an evaluation of damage caused on road structural pavements by utility service providers in Rwanda. This study was undertaken to evaluate the damage caused to structural pavements by utility service providers in Rwanda.

1.2 Statement of the problem

The majority of utility service provider’s infrastructure lies underground often partly or wholly beneath road pavements. Rwanda roads structural pavements are getting dilapidated by the activities and practices of utility services providers. Utility service providers make utility cuts in order to lay pipes and other utility lines such as water pipelines, storm water pipes, electric cables, sewer lines, telephone lines, optical fibre cables, network lines and other construction related works. Utility cuts reduce roadway life considerably, loss of roads beauty, resulting into patched surfaces on the pavements and impairing performance of the original pavement. Road structural pavements are characterized by a multiplicity of road distresses, cuts by utility service providers and not repaired in time and those repaired fail prematurely. During repair a lot of dust is raised which is a public nuisance and always result into unnecessary traffic jam.

They also affect performance of the existing pavement and result into increased maintenance and repair costs (Tie water, 1997). Utility service providers also cuts roads to provide new or extended networks of pipelines or ducts, increase existing network capacity; transfer services from above the ground to below the ground, replace defective pipelines, and rehabilitate existing pipelines. The Rwanda Transport Development Agency (RTDA) states that utility services providers before excavating road structural pavements, seek for permission from them or City of Kigali at a cost for reinstatement. The destruction of pavement layers affects the quality and nature of road structural pavements and substandard materials are used to replace the previous old ones. The quality and life span of roads in Rwanda is highly compromised by these activities.

1.3 Objective of the study

The general objective of this study was to evaluate the damage caused to road structural pavements by utility service providers in Rwanda.

The specific objectives were:

i. To assess the road surface damage (cracks, depressions, potholes, and bleeding) caused by utility related cutting and their progression overtime;
ii. To evaluate the practices of Contractors when selecting materials for repair of utility cuts and compacting pavement layers;
iii. To establish the resultant effects of repaired utility cut distresses on the road users, road sector and road pavements;
iv. To recommend the best practices that can be adopted to reduce repaired cuts distresses on the road pavements.

The research questions were:

1. What are the types of road distresses resulting from road cutting by utilities service providers and their variation in measurement in a three methods period?
2. What are the practices adopted by Contractors when selecting materials for repair and compacting pavement layers?
3. What are the resultant effects of repaired utilities cuts distresses on the road structural pavements?

4. What are the best practices to adopt in reducing utilities cuts distresses onto the road pavements?

1.4 Significance of the study

The study will bring forth enhanced understanding and information to Rwanda Transportation Development Agency (RTDA) and City of Kigali (CoK) regarding the damage to the road structural pavements due the activities of utilities service providers. The study would also provide guidance on the best restoration and installation methods of utilities cuts.

The model in Figure 1 below shows the interrelation between utilities service providers and road authority's.

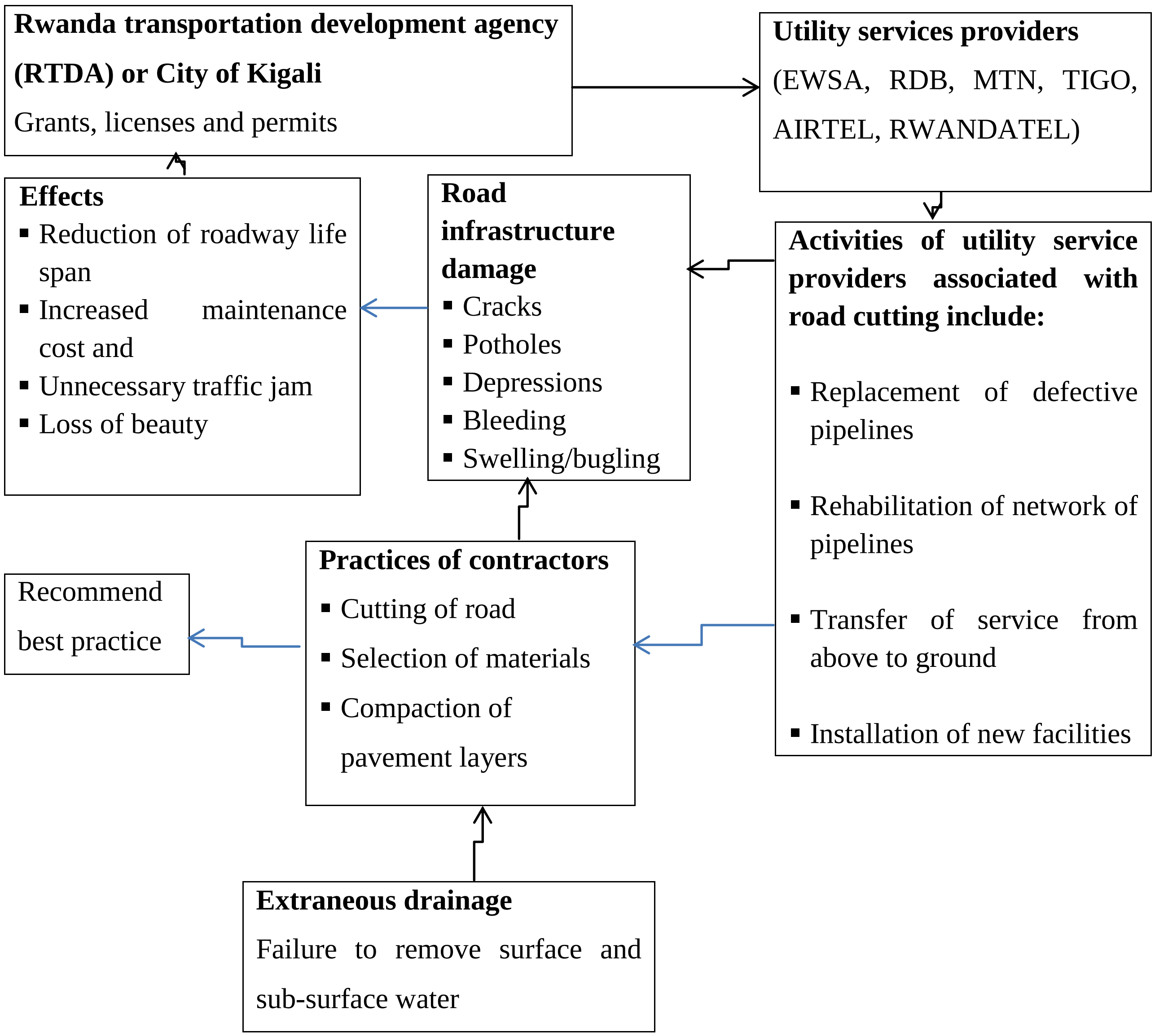


Fig. 1 Conceptual framework relating to the dependent and independent variables in the study.

1.5 Scope of the study

Geographically, the study covered selected roads in Kigali City area because most paved roads are highly dilapidated and damage by the activities of utilities service providers. The Kigali City therefore offered a feasible platform to undertake study. In content, the study focused on relating damage to road structural pavements in Kigali and the activities of utilities service providers.

1.6 Structure of the Thesis

The structure of this thesis is consisting six chapters. Chapter one is introduction of my thesis. This chapter is composed by background, statement of the problem, objective of the study, significance of the study, scope of the study and structure of the Thesis.

Chapter two is literature review. This chapter is mainly consisting of road surface and subsurface distresses due to cuttings, current practice on utility cuttings across roads, best practices to reduce repaired utility road cut distresses, effect of repaired cut distresses on road infrastructure, road drainage and summary of literature review.

Chapter three is methodology. This chapter is how research has been done, research design, data collection methods and tools, validity and reliability of data, field tests and laboratory tests, data analysis and presentation,

Chapter four is data collection and processing. This chapter is consisting of types of data collected, laboratory tests and how was processed for analysis.

Chapter five is data analysis and discussion of results. This chapter is consisting of analysis of processed data, discussion of results and summary of findings.

Chapter six is conclusion and recommendations. This chapter is consisting of conclusions, recommendations and areas of further research.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This section reviews literature related to respective specific objectives in this research. This research will be basically looking on the problem of damage caused to road structural pavements by utility service providers. This chapter will review on the road surface and subsurface distresses due to cuttings, potholes and cracks, bleeding, depressions, current practice on utility cuttings across roads, selection of subgrade materials and compaction, compaction of subgrade, selection of sub base materials, compaction requirements for sub base, road base materials, wearing course materials, procedure of utility cut repair, best practices to reduce repaired utility road cut distresses, effects of repaired cut distresses on road infrastructure and road drainage. Utility cuts had increased budget for maintenance costs, unnecessary traffic jams and reduction of roadway life.

2.2 Road surface and subsurface distresses due to cuttings

Hawi Asphalt pavement industry (2003) points out that surface distress is an indication of poor or unfavourable pavement performance or signs of impending failure. The surface and subsurface distresses include; cracks, potholes and bleeding visible on many road structural pavements in Rwanda.

2.2.1 Potholes and cracks

Hawi Asphalt pavement industry (2003) points out that cracks are a series of interconnected openings caused by fatigue failure of the asphalt surface under repeated traffic loadings. As the number and magnitude of loads becomes too great, longitudinal cracks begin to form usually in the wheel paths. After repeated loading, these longitudinal cracks connect forming many sided sharp angled pieces that develop into a pattern resembling the back of an alligator or crocodile. Surface potholes are the result of fatigue cracking. As fatigue cracking becomes severe, the interconnected cracks create small chunks of pavement, which can be dislodged as vehicles drive over them. The remaining hole after pavement chunk is dislodged results into pothole. Roberts (1996) cited in Hawi Asphalt pavement industry (2003) states that potholes are small, bowl shaped depressions in the pavement and they generally have sharp edges and vertical sides near the top of the hole. Potholes are most likely to occur on roads with thin asphalt surfaces (25mm to 50mm) and seldom occur on roads with 100mm or deeper asphalt surfaces.

Photo 2: Multiples of repaired utility cuts for different companies bearing pothole, cracks and depressions

The potholes and cracks resulting from activities of utility service providers as shown in above picture are readily visible on road structural pavements in Rwanda, many of which are varying in measurement overtime, but this is not ascertained.

2.2.2 Bleeding

Hawi Asphalt pavement Industry (2003) states that, the bleeding occurs when an asphalt binder fills the aggregate voids during hot weather or traffic compaction, and then expands onto the pavement surface. Since bleeding is not reversible during cold weather or periods of low loading, asphalt binder will accumulate on the pavement surface over time. The likely causes are; excessive asphalt binder in the low hot mix asphalt either due to a poor mix design or manufacturing problems, excessive application of asphalt binder, low hot mix asphalt, air void content and a mix design problem. Several bleedings are viewed on different roads in Rwanda with variation in coverage overtime. Distinction cannot be made between bleeding caused by repaired utility cuts of utility service providers and those caused by others on the same paved roads in Rwanda.

2.2.3 Depressions

Hawi Asphalt pavement Industry (2003) defines depressions as small localized areas that are caused by subgrade settlement resulting from inadequate compaction during construction. Depressions are very noticeable after heavy storm when they fill with water. Depressions on different road structural pavements in Kigali are visible as per below pictures. The causes of the depressions are not disclosed. Depressions evidently vary in measurement overtime however, this has never been investigated.

Photo 3: Utility cut, not repaired, with depression

Photo 4: Utility cuts, repaired but not well compacted

Photo 5: Repairing the utility cuts

Photo 6: Compaction of asphalt on the utility cuts

2.3 Current practices on utility cutting across roads

Installation of utility service provider's infrastructure underneath road structural pavement and restoration works are done by contractors on behalf of utility companies. Michael (2009) defines a contractor as anyone who agrees to fulfil the terms of a legally binding agreement. Amarjit et al., (2006) also define a contractor as a person or firm, giving an undertaking for the execution of any work or supply of materials or performance of any service in that connection. Taking into above definitions, we agree with the above citation and define contractor as a person or firm who bid to carry out works that has been accepted by the employer. The term contractor is used to describe an expert in the construction industry who hires skilled and unskilled workers to actually construct a financed project. The term structural pavements covers subgrade, sub base, road base, asphalt base, surface materials and surface dressings.

2.3.1 Selection of subgrade materials compaction

Transport research laboratory (1993) describes subgrade materials that provide cover to weak subgrades. They are used in lower pavement layers as a substitute for thick sub-base to reduce costs at a minimum of 15% California bearing ratio (CBR) is specified at the highest anticipated moisture content at a 90% of minimum density usually specified. The strength of road subgrades is commonly assessed in terms of the California bearing ratio (CBR). It is noted that California bearing ration (CBR) depends on the type of soil, its density and its moisture content. After estimating the subgrade moisture content for design, it is possible to determine the appropriate design California bearing ratio (CBR) value at the specified density. Transport research laboratory (1993) recommends 250mm of subgrades be compacted during construction to a relative density of at least 95% of the maximum dry density achieved in the British Standard Compaction Test, 2.5kg rammer method. Compaction improves the subgrade bearing strength and reduces permeability and subsequent compaction by traffic. It is important to ensure good compaction during construction to achieve long term performance of the road as a way of preventing the negative effect that results into distresses. Photo 7 shows the repair of utility cuts.

Photo 7: Repair of utility cuts

Transport research laboratory states how the materials for subgrade are selected, the benefits towards use of specific materials and compaction levels. Rwanda transportation development agency (RTDA) provides the factors considered in estimation of actual moisture content of the sub grade soil under paved roads. These include; local climate, depth of water table, type of soil, topography and drainage, permeability of the pavement materials and permeability of the shoulders. Rwanda transportation development agency (RTDA) asserts that estimating the wettest moisture content should occur for the purpose of determining the design subgrade California bearing ratio (CBR) and emphasizes that moisture content in sub grades is prone to variation due to natural effects like rainfall, evaporation, and proximity to water table. A multiplicity of repaired cuts on roads structural pavements in Rwanda bear distresses whose causes necessitate an evaluation. For a rational approach to pavement design, the most important characteristic of the subgrade is its elastic modulus. However, the measurement of this modulus requires fairly complicated and time consuming tests. It is has been approved that there is good correlation between the California bearing ration (CBR) and the elastic modulus of the soils. Since the CBR test is fairly easy and widely used test, it has been decided to retain it as the quantitative means of evaluating the sub grade bearing strength.

Table 1: Sub grade bearing strength classes

Soil Class	CBR Range	Median
S1	2 - 5	3.5
S2	5- 10	7.5
S3	7 - 13	10
S4	10 - 18	14
S5	15 - 30	22.5
S6	30	

Source: Ministry of the transport and communication (Kenya), Road Department, Road design manual (1987)

The above ranges California bearing ratio (CBR) ranges correspond to the results actually obtained on materials of the same type along sections of road considered homogeneous. They reflect both the variations of the characteristics of the soil which inevitably occur, even at small intervals, and the normal scatter of test results. The strengths of soils lies in the difference of the California bearing ratio (CBR) percentages ranges as indicated in the table above.

The design manual states that the selection of sub base materials depends primarily on the design function of the layers and the anticipated moisture regimes. It is also advanced that a wide range of materials can be used as unbound road bases including crushed quarried rock, crushed and screened, mechanically stabilized, modified or naturally occurring as dug gravels. It is argued that their use depends principally on the design traffic levels of pavements and climate. Furthermore, road material, particle size distribution and particle shape, which provide a high mechanical stability and contain 4% sufficient fines (Kenya design manual) as per above table.

2.3.2: Compaction of sub grade

BS 1377-4:1990 defines compaction of soil as a process by which solid particles are packed more closely together, usually by mechanical means, thereby increasing its dry density. It is also stated that the dry density, which can be achieved, depends primarily on the degree of compaction applied and the amount of water present in the soil. For a given degree of compaction of a given cohesive soil, there is an optimum moisture content at which the dry density obtained reaches a maximum value. For cohesionless soils, optimum moisture content might be difficult to define. This compaction is not specific to any layer.

Table 2: Sub grade depth

	Sub grade Class designation					
	S1	S2	S3	S4	S5	S6
Minimum Depth (mm)	250	250	350	450	550	650

Source: Ministry of work, housing and communication, Uganda (2005)

In addition to above table, it is encouraged to determine the minimum depth and relative compaction of each soil class of material. It is advisable that in case of insufficient compaction during construction, then longer performance of the road is likely to be negatively affected. It is critical to ensure that good compaction is attained for different soil classes considering the environmental climatic changes. Furthermore, Ministry of Transport and Communication, Uganda (2005), provides compaction requirements during construction as follows; the upper 300mm of subgrade are compacted to a dry density of 100% in cutting where there is no improved sub grade and all fills. It is further stated that improved sub grade placed at upper 150mm of sub grade prior to placing of improved sub grade layers compaction should be at least at 100% MDD and the lower 150mm to at least 95% MDD. It is recommended that all improved sub grade should be compacted to a dry density of at least 100% MDD. It is further stated that the maximum compacted thickness paid, processed and compacted at one time set at 300mm and the moisture content at same time should not exceed 105% of the optimum moisture content. It is advantageous to obtain relative compactions higher than the above figures, since compaction does not only improve sub grade bearing strength, but also reduces permeability.

2.3.3: Selection of sub base materials

Sub base materials is defined as secondary load spreading layer underlying the road base and that the sub base prevents contamination of road base materials and protects the sub grade from damage by construction traffic. Furthermore, the sub base layer consists of materials of lower quality than the road base and their choice depends on the design function. Two types of materials as predominantly used are natural gravel and graded crushed stone.

Natural Gravel

This consists of a wide range of materials including lateritic gravels, quartzite gravel, calcareous gravel and some forms of weathered rocks, soft stones coral rag and conglomerate through similar to sub grade materials. These materials have a California bearing ratio (CBR) of at least 30% at 95% maximum dry density (MDD).

Graded crushed materials

The graded crushed materials are resorted to in absence of suitable natural gravel materials. Ministry of works, housing and communication (2005), Uganda cites abundance of graded crushed stones and that usage depends on the following; material requirement, traffic limitations and construction procedures. It further recommends that fairly coarse crusher run (0/6mm) is economical and may be used for medium and light traffic class. The general requirements are that fines must be non-plastic. Ministry of works, housing and communication (2005), Uganda specifies the required amount or percentages of fines to safeguard against segregation of graded crushed stones. It is however noted that graded crushed materials be kept moist during handling, transportation, laying and should not be stock piled more than 5.0m high. Different manuals specify different percentages fines. This study will evaluate the amount of fines used by Contractors in repair cuts.

Ministry of works, housing and communication (2005), Uganda, provides similar types of material but further highlight the overriding requirement to achieve the minimum design soaked California bearing ratio (CBR) of 80% at the probable in situ density and moisture content conditions, and preservation of strength in service or long term durability without undesirable volume change in materials. It also states that the required performance cannot be consistently achieved by a particular as dug material. It is hence suggested that the aggregation of materials from different sources is permissible to achieve the required properties and may include; addition of fines or coarse materials or combination of the two.

However, Ministry of works, housing and communication (2005), Uganda, does not provide the standards for selection of materials for repair of utility cuts on road structural pavements, neither does it stipulate the compaction standards. Rwanda transport development agency (RTDA) does not also provide materials standards for repair of utility cuts. Ministry of works, housing and communication (2005), Uganda, emphasizes the conventional standards to select materials and minimum thickness of compaction for sub base of 100mm and a maximum of 200mm with compaction moisture content ranging between 80-105% of optimum moisture content. The manual does not bare strategies of ensuring adherence by the Contractors.

2.3.4: Compaction requirements for sub base

Traffic classes and ranges

Road design manual, Kenya (1987), provides ranges of traffic classes to ensure appropriate choice of traffic boundaries. It is also suggested that the classified traffic categories and the cumulative equivalent standard axles (ESA) guide the design of pavements structures. It also provides traffic classes and ranges as shown in below tables, is in agreement with the classes tabulated. It provides similar traffic ranges that guide design procedures for compliancy and the design standards of roads parameters.

Table 2: Traffic classes

Class	**Cumulative number of standard axles**
T1	25 million – 60 million
T2	10 million – 25 million
T3	3 million – 10 million
T4	1 million – 3 million
T5	0.25 million – 1 million

Source; Road design manual, Kenya (1987)

The above traffic classes correspond to the following initial daily numbers of standard axles.

Table 3: Traffic classes and ranges

Traffic classes	**Ranges (10^6 ESA)**
T1	<0.3
T2	0.3-0.7
T3	0.7-1.5
T4	1.5-3.0
T5	3.0-6.0
T6	6.0-10
T7	10-17
T8	17-30

Source; Transport research laboratory, Uganda (1993)

Aggregate classifications

There are traffic classes in relation to the required stone classes and level of granularity. Ministry of Transport and communication, Uganda (2000), provides the classifications of aggregates for the different traffic classes as shown in Table 5.

Table 4: Stone classifications

Traffic class	**T1**	**T2**	**T3**	**T4**	**T5**
Stone class required	A	B	B	C	C
Granularity required	0/40	0/40	0/40-0/60	0/40-0/60	0/40-0/60

Source; Ministry of Transport and communication, Uganda (2000)

Selection of stone crushed sub base materials are determined basing on the measurements as shown in Table 4. Furthermore, it is argued that graded crushed stones are considered unsuitable for traffic class T1 or for roads carrying overloaded axles. Generally 0/40mm is recommended for grading and it is further argued that for traffic class T2, it is necessary to use 0/30mm graded crushed stone in order to minimize segregation and provide sufficient stability. A minimum amount of fines of fines of 4% is considered necessary to ensure stability of the base. For insufficient amount of fines produced during crushing operation, angular sand may be used to make up the deficiency, aiming at achieving maximum impermeability compatible with good compaction and high stability under traffic.

Compaction requirements

Ministry of Works, housing and communications, Uganda (2005), employs the Dynamic Cone Penetrometer (DCP) to determine and monitor penetration rates, in the process of checking the field compaction at specific depth. Where the rate of penetration exceeds acceptable specific maximum values, further compaction is necessary. Ministry of Transport and communication, Uganda (2000), recommends compaction of sub base as follows; minimum thickness of layer 125mm, average dry density ranges 85 – 98% and moisture content between 80 – 105% optimum moisture content using vibrating hammer. It is suggested that the maximum thickness compacted in one layer should be set at 200mm. In addition to the above, it is argued that laboratory compaction tests on materials containing more than 25% of particles greater than 40mm cannot be accurately carried out. It is further stressed that dry compaction by vibratory rollers operating at the proper frequency and amplitude give fairly good results on some non-plastic materials. The above recommendations are in line with Ministry of Works, housing and communications, Uganda (2005). However, it is uncertain about the practices of Contractors towards adherence to compaction standards as specified in the above manuals.

2.3.5: Road base materials

Materials used for sub base layers are similar to those for road base pavement layers but differ in functions and thickness. The same material selection and construction procedures under sub base layers apply to road base suitability and their use depends primarily on the designed traffic levels of the pavement and climate. In addition, it is noted that all road base materials must have a particle size distribution and particle shape which provide mechanical stability and should contain sufficient fines passing 0.425mm to produce a dense material when compacted (Transport research laboratory, Uganda (1993). This agrees with Ministry of Works, housing and communications, Uganda (2005), which states that in modified or occurring gravel, there is need for stabilization using lime or cement to improve on the inadequate material properties.

Stabilization of bases

Different design manuals provide specifications for the different types of stabilization materials, the amount of percentage application, temperature, and duration allowable for finishing and completing compaction, which affect the strength, durability and performance of structural pavements of road bases. The nature of road base materials used is selected according to locality, climate and environmental conditions as cited by Punmiaet al(2005). Table 6 below provides information on the strategies used for road base stabilization.

Table 6: Strategies for base stabilization (Punmia et al 2005)

Method	Notes
OPC	Less cement content (5% or more) with PI < 10, seven (7) days moist curing at 25^0C, strength testing before soaks at 4 hours, two (2) hours finishing and completing compaction (MOWHC, 2005) while 3-6% for plastic gravel and 3-5% for clayey sands without any addition (MOTC, 2000)
Hydrated lime	Hydrated calcium lime 4-6% with PI > 10, four (4) hours for finishing and completing compaction eleven (11) days for moist curing instead of seven (7) days and further four (4) hours soaking at same temperature and allowable seven (7) days for minimum strength limits (MOTC, 2000 & MOWHC, 2005)
Bituminous emulsion	Natural gravels and in situ materials applied in 1-3% by weight combined with the addition of 1% bituminous emulsion

Ordinary Portland cement

Ministry of Works, housing and communications (MOWHC), Uganda (2005), recommends use of less cement contents (5% or more) to reduce cracking. It also suggests materials suitable for cement treatment as that which has Plasticity Index (PI) less than 10 with reasonably uniform grading. It is further argued that materials with higher PI can be first treated with lime (modified), prior to cement treatment. Seven days (7) moist curing at 25^0C should be allowed and strength testing then soaking for four (4) hours at the same temperature. Two hours (2) are recommended for finishing and completing compaction. Ministry of Transport and communication, Uganda (2000), recommends use of ordinary Portland cement without any addition. The amount required for plastic gravel range between 3-6% and for clayey sands, it should be 3-5%.

Hydrated calcium lime

Ministry of Transport and communication (MOTC), Uganda (2000), stipulates that 4-6% hydrated calcium lime is usually required and four (4) hours allowance for finishing and completing compaction. This is supported by Ministry of Works, housing and communications, Uganda (2005), which pinpoints lime as more effective on many materials with high PI greater than 10. Two categories of lime are used namely; hydrated and un hydrated (quick). However, quicklime is strongly cautioned against due to health risks and its use for road building is banned in a number of Countries. Eleven (11) days allowed for moist curing instead of seven (7) days and further four (4) hours soaking at same temperature as for cemented materials. Seven (7) days minimum strength limits is allowed for this purpose.

Bituminous emulsion

Ministry of Works, housing and communication (MOWHC), Uganda (2005), has indicated that bituminous emulsion treatment has proved to be effective for range of materials, leading to significant improvement in strength and durability. The nature of reaction is still unclear but proven to aid compaction in road buildings characteristics of natural gravels and in situ materials applied in 1-3% by weight combined with addition of 1%. In South Africa, bituminous emulsion has been in use for more than 10years carrying out substantial traffic and no failure has been reported. It is advisable to consider inclusion of trial sections for establishment of its performance for a particular locality.

Compaction of road base materials

Compaction is defined as a process by which the particles are artificially rearranged and packed together into a closer state of contact by mechanical means in order to decrease the porosity (or void ratio) of the soil and thus increase its dry density (Punmia et al 2005). It is argued that the compaction process is accomplished by rolling, tampering or vibration in the field. Compaction for a particular construction material varies in the field in three aspects namely; water content, amount of compaction and type of compaction. It is in this context that a definite relationship exists between soil water content and degree of dry density to which the soil might be compacted, and that for a specific amount of compaction applied on the soil, this is termed as "optimum water content" at which a particular soil attains maximum density. In the field, compaction is controlled by water content, dry density and the degree of compaction. Addition of admixtures modifies the compaction properties/characteristics of the soil.

There is design manual which states that compaction using cement and lime as stabilizer, improves the structural strength and properties road construction materials. The road base should take the following forms; minimum thickness of compacted layer should be 125mm and a maximum in one layer should be 200mm, normally 95% MDD and mixing should be by pulvimixer or travel plant. At compaction, the recommended moisture content should range between 80-105% OMC. However, variances are noticed in the thickness of pavement layers for different soils classes from different design manuals. Need arises to establish guiding principles necessary to help Contractors when selecting and compacting materials for repair of road utility cuts.

It is recommended that eight (8) practical hours for protection and curing of lime and four (4) hours for cement. It is further recommended that no traffic should be permitted for the first seven days. There are discrepancies or gaps in the curing duration for the two stabilization materials and the time required to permit traffic must be addressed to prevent premature failure to repaired utility cuts.

2.3.6: Wearing course material

GurcharanJagdish (2004), states that the mix after spreading should be thoroughly compacted by a set of rollers at a speed not more than 5km/hr. The initial or break down rolling should be 8-12 tons, surface finished by final rolling with 8-12 ton tandem roller. However, before finishing, it is good that breakdown rolling be followed by an intermediate rolling with fixed pneumatic roller of 15-30 tons and having pressure of $7kg/cm^2$. It is also argued that traffic may be allowed immediately after completing final rolling and after the surface has cooled down to atmospheric temperature.

The failure to maintain surface dressing is likely to lead to a reduction in pavement life due to effects of trafficking and aging of the binder. It is considered that heavy pneumatic tired rollers for kneading action as important in orientating the particles. Vibratory compaction has been used successfully but with care in selecting the appropriate frequency and amplitude of vibration. However, steel wheeled dead weight rollers are discouraged as they give rise to a smooth surface with poor texture.

The Contractors when completing repair of road utility cuts on road structural pavements are supposed to cover the primed surface with wearing course. However, in Rwanda when repairs are done, at times utility cuts remain uncovered without any wearing course. If it is covered, they fail prematurely and lead to distresses. Alexander et al., (1999) observed that there is no generally accepted test method or methods to determine the long term performance of a material to be used for surface repairs. The most important material properties in this respect are likely to be those related to the various types of deformation: shrinkage, creep, modulus of elasticity, and coefficient of thermal expansion. However, there is no agreement on the relative influence of each of these properties.

The Rwanda transport development agency (RTDA) determines which materials are suitable for its particular environment and working conditions as some materials have tight working tolerances, such as air temperatures and surface wetting conditions during placement, mixing quantities and times, and maximum depths of placement. Materials specifications must be carefully consulted during materials selection. Material cost, shelf life, physical properties, workability, and performance vary greatly among the different types of materials, and from brand to brand within each type. When comparing costs, the initial material cost plus the cost of installation in terms of time, equipment, and labour must be considered (Wilson et al., 1999).

2.3.7: Procedure of utility cuts repair

Allan (2007) points out that to perform a proper remove and replace repair, which generally extends about 100mm deep, the following steps should be taken into account. These are:

a. Excavate the area to a depth necessary to reach firm support. In many cases, this means removing the base and often removing some of the sub grade. Failure to remove all unstable material assures the patch will fail as shown in below picture;
b. Extend your repair at least 300mm into the structurally sound pavement surrounding the damaged area;
c. Square up the repair, making sure it is rectangular. Some Contactors use a jackhammer to cut the edges and square up the hole, but a pavement saw is generally faster and results in a cleaner cut;
d. Apply a tack coat to the vertical faces of the cut. This helps the hot mix stick better to the sides of the patch, making the patch stronger by bonding it to the existing pavement.

Photo 8: Utility cut

The view above not based on an evaluation of selection of materials and compaction of wearing course.

Lubega (2008) found out that Companies get contracts and do substandard work. He also noted that the causes of poor roads is the cumulative number of vehicles that operate day and night yet the materials used to mend the roads are not durable. He, however, does not define the materials used and level of compaction of the different layers.

Walaa and Elhussein (1999) studied the restoration practices and found out that by then, Contractors had neither a mechanism to evaluate the impact of digging and soil removal nor design or construction specifications to reduce its effects. In addition, the sensitivity of digging and compaction equipment to the characteristics of utility cuts was not well investigated. It further stated that the flouting engineering procedures and principles is the main cause of utility cut restoration problems.

In addition, it is advanced that tight workspace dictates the use of equipment smaller than that used in the construction of conventional roads. Furthermore, it is revealed that there are many innovative materials such as flowable fills and soil modifiers whose characteristics and behaviour deviate from standards established by the American Association of State Highway and Transportation Officials (AASHTO).

Surface dressing

It is stated under Ministry of Transport and communication, Uganda (2000), which for the surface dressing, prime coat and tar coat of low viscositybituminous binder is applied to an absorbent surface to act as waterproof and bind the overlying bituminous course. The most appropriate binder for priming comprises fluid of the medium curing fluid cutbacks moisture content (MC 30) and MC 70. Its application depends on the texture and the density of the material to be primed and usually sprayed at a rate ranging between 0.8 – 1.2 litres/m^2.

Gurcharan and Jagdish (2004) considers bituminous concrete pavement to be of highest quality construction, proportioned to dense mixture of coarse aggregates, fine aggregates, filler materials and bitumen. Table 7 below provides recommended thicknesses of binder and wearing course to different nature or losses of traffic.

Table 7: Recommended thickness of wearing course

Nature of traffic	**Thickness in (mm)**		**Total thickness (mm)**
	Binder layer	**Wearing layer**	
Very heavy traffic	60 – 80mm	40 - 25	100
Heavy traffic	40 – 50mm	40 - 25	80
Medium traffic	40 – 50mm	40 - 25	80
Light traffic	No binding lay provided	50	50

Source: Gurcharan and Jagdish S 2004

2.4: Best practices to reduce repaired utility road cut distresses

Jones (1999) proposes that to conduct any utility works project involving the installation of underground facilities, two alternatives for access are available to do the works namely; trench less technology and open cut & restore techniques. Trench less technologies are attractive in that they cause minimum disturbance to traffic and have a low impact on the environment and least inconvenience to the public. He reports that more than 100,000 utility cuts are dug and the roadway restored every year in Camden Borough a District of London, UK. A similar yet more staggering finding is that more than 250,000 utility cuts a year are made in the streets of New York City. This number increase by 8% each year. These statistics and many more, serve to confirm and substantiate the fact that there is definitely an increase need to access the underground facilities for maintenance and rehabilitation of the aging systems.

Walaa and Elhussein (1999) noted that every day a substantial number of utility cuts are dug and restored in every city worldwide either to install new services or to repair and upgrade existing facilities. The process of restoration is hindered by risk of construction failures due to unexpected underground obstacles or sandy soil conditions. Limitations exist including boring equipment, size of pit hole, minimum offset from street curb, maximum length of boring span, availability of skilled equipment operators, absence of maps or drawings that provide accurate underground information and high initial cost and short history of proven success. The observations above were not focused towards best practices to reduce utility cut distresses.

Jones (1999) further mentions that a successful construction practice dealing with restoration of utility cuts should include structural design approach based on sound engineering fundamentals, material selection based on known material response to external stimuli, well defined failure mechanisms and quantifiable performance based on predictable indicators, and controlled in-field practice involving construction equipment usage and reliable construction specifications that can be related to performance of the system.

Trevor. M (2006) states that one of the main inefficiencies associated with the current regime is lack of coordination between the various utility service providers that need to access pipes and lines running underneath roads. Changes from cuts, open and restore to trenchless technique of utility installation will see reductions in compliances costs through initiatives such as the introduction of national standards, reduced costs for local Government through less damage to roads and drains, and also benefits to communities through fewer road accidents. It is advanced that tight workspace dictates use of equipment smaller than those used in the construction of conventional roads. It is recommended that utility companies that operate in the public right of way to coordinate between themselves and public road authorities to ensure responsible utilization of public resources by parties involved. Furthermore, the following proposals are put forward; consideration in the reinstatement strategy, public safety, riding comfort, aesthetics and cost effectiveness. There is no existing information regarding the above practice in Rwanda.

Walaa and Elhussein (1999) observed that through utility cuts are normally restored based on specific design and construction practices, they continue to perform poorly in many cases. It is recommended that to reduce confusions of various reinstatements, some important issues must be considered namely; joint research ventures that involve both parties and development of performance based specifications to solve the conflict between municipalities and utility service providers while considering the requirements of management.

2.5: Effects of repaired cut distresses on road infrastructure

Alick (2002) cited in the New Zealand utilities Advisory Group (2003) reported that, over 1000 trenches in Wellington were not reinstated properly. Alick, further observed that, it is estimated that digging up a road even once reduces life of the pavement by 30%. This is also supported by Bodocsi (1995) where it is pointed out that a new asphalt pavement lasts from 15 to 20 years. Furthermore, Bodocsi (1995, pointed out that once a cut is made, the pavement life is reduced to about 8 years in the area of the patched pavement. Tie water (1997) is also in agreement with Bodocsi (1995) who states that several excavations in pavements by utility companies can reduce road life by 50% as per below picture .

Photo 9: Repaired utility cut with extended pothole and cracks that affect road life and serviceability

The observations of Alick (2002) and Tie water (1997) are not focused towards establishment of the effects of distresses such as potholes, bleeding, cracks and depressions on road users, road sector and road pavements.

Walaa an Ejhussein (1999) established that utility works in the United Kingdom rank as the second major cause of traffic disruptions with estimated delay costs of $ 13 billion dollars. It is pointed out that over the past 50 years, many studies carried out by several municipalities and utility companies have indicated that the life expectancy of an urban street may be reduced by utility cuts. Although there is no agreed upon quantitative evaluation of the effects on pavement life, a strong perception on the part of public road authorities is that roadway performance is adversely affected by reinstate utility cuts, which result into increased maintenance costs to public agencies. The findings above are in line with those by the New Zealand Utilities Advisory Group (2003) which states that digging up streets one after another makes pristine routes to begin to look like patchwork quilts as Contractors reinstate roads with little forward planning. These achieve substandard outcomes as utility providers and consumers get frustrated when third party damage to the pipes and lines disrupts services. The effects of utility cuts distress posed to the road sector, users and road pavements in Rwanda is short of evaluation.

Jones (1999) observed that there was an increasing need to access underground facilities for maintenance and rehabilitation of aging systems and in turn crates serious financial stress on cities and utility companies.

2.6: Road drainage

Road drainage relates to collection and evaluation of water present in subgrade and pavements. The mechanical characteristics and performances of pavement diminish overtime in the presence of surface and subsurface water (Road Drainage Technical Guide 2007). Active Web Corporation (2010) defines drainage as the removal of excess water from high water table or water that infiltrates the road surface into the base and sub- base through cracks. Many roads failures and extensive poor performance are attributed to inadequate road drainage. National Cooperative Highway Research Program (CHRP), USA (1997) points out that surface and subsurface drainage is a key element in the design of pavement systems and that indiscriminate exclusion of this element assuredly leads to premature failure of pavement systems. The strength of substructures and the service period of roads are highly influenced by intrusion water. Hence, provision of well-planned and designed storm water drainage is a basic requirement in almost all road projects. However, the study treated road drainage as an extraneous valuable to utility road cut distresses subject to further research.

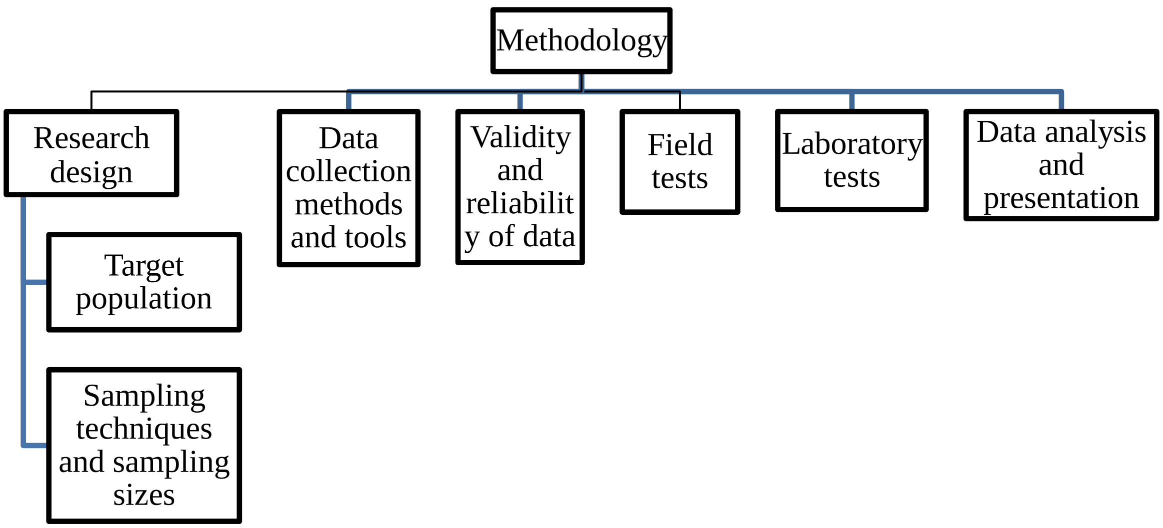
2.7: Summary of Literature Review

Although not taken seriously, installation of utility cuts in pavements has a lot of bearing of road performance. Activities involved in installing facilities under or over road structural pavements and the restoration process results into surface and subsurface distresses like; potholes, cracks, bleeding, depressions and others. However, literature has not indicated how distresses vary overtime and the damage that is specific to utility cutting of roads explicitly. Most of the information available relates to specific standards, procedures and methods for selection of materials including compaction of structural pavement layers for construction of new conventional roads but do not provide specifications for repair of cuts when Contractors are installing utilities. Several methods highlighted focus on mitigation measures to reduce road cutting and eventual resultant effects on the road users, road sectors and road pavements. It is acknowledged that all authors proposed possible scientific alternatives but do not recommend the best appropriate restoration methods to reduce utility cut distresses. This results in a multiplicity of maintenance costs, unnecessary traffic jams and reduction in roadway life. This study focused on surface and subsurface distresses including their progression over time; selection and compaction of materials for repair of utility road cuts; the resultant effects of repaired cut distresses on road users, road sector and road infrastructure in Rwanda and hence recommend the best practice.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter gives the methodology that was employed in this research. The methodology used comprises of literature review, questionnaire survey to technical staff, research design, data collection methods and tools, validity and reliability of data, field tests and laboratory tests, data analysis and presentation.



3.2 Research design

The study adopted a quantitative approach based on categorical variables analyzed with preferred statistics (Creswell, 2003). Respondents were systematically drawn from employees of utility services companies, City of Kigali (CoK) and Rwanda Transport Development Agency (RTDA).

3.2.1 Target population

The study targeted 400 technical personnel from the list of utility companies, contractors and road sectors (City of Kigali and RTDA) in Kigali. The respondents included civil engineers, foremen, technical supervisors of road structural pavements and utility service provider's personnel. The respondents were selected because of their great involvement in the aspects of network development, quality enhancement and supervision of road infrastructural development.

3.2.2 Sampling techniques and sampling sizes

The researcher used two stage cluster samples, the first stage permitted identification of different utility service providers, contractors and road authorities and these were grouped into six clusters, a representative sample of three clusters were selected from six clusters using simple random sampling as per below table.

Table 5: Utility service providers

Serial number	**Name of cluster (6)**	**Name of (3) cluster**
1	A1	B1
2	A2	
3	A3	B2
4	A4	
4	A5	B3
6	A6	

Computer generated random numbers were assigned to each respondent and a sampling frame was got from each chosen cluster and sampling units were listed. Technical personnel from each of the three clusters are represented. Modified of Kish and Leslie (1965) was used to determine the sample size as below:

$$n = \frac{(Z^2 \times P \times Q \times Deff)}{E^2}$$

Where:

n = Sample size

Z = Standard normal variant at the acceptable level of significance of 95% which is 1.96

P = Proportion of technical staff in a sample of clusters (400) chosen from six clusters

Q = Proportion of non-technical staff in all six clusters (96) selected from 196 staff of road sector, contractors and different utility service providers

E = Acceptable error estimates of technical staff allowing an acceptable error of 0.09 (9%)

Deff = Design effect taken to be two as recommended by World Bank for social Economic surveys, (1996). The nine clusters comprised of 196 total number staff of which 100 technical staff were targeted and 340 non-technical staff

Therefore P = 400/760 = 0.53

Q = 360/760 = 0.47

n = (1.96^2 x 0.53 x 0.47 x 2)/0.09^2 =236 respondents, since three clusters were chosen, therefore 79 respondents represented each cluster.

Share of cuts, forms of distresses and variations

A sample of five roads was determined from a population of 10 roads for which permits were granted for road cutting and repair. A sample of 28 repaired utility cuts was identified, measured with the use of a steel tape and observation made for a three (3) month period on the five (5) roads.

Wearing course thickness for different traffic levels

A sample of 5 roads was determined from a population of 10 roads for which permits were granted for road cuts. A sample of 12 repaired utility cuts on different roads and the repaired utility cuts at potholes were purposively identified and measured with a straight edge and steel ruler.

Effects of repaired utility cut distresses

On roads (road life span), distresses on three (3) traffic junction in Kigali were identified and observed. Road users (traffic jam), a road with a pothole was purposively selected and sample of 25 vehicles along and towards the pothole were timed.

3.3 Data collection methods and tools

To ensure accuracy of the data collection instruments, an independent cluster that did not participate in the main survey was used. Observation sheets and a structured administered questionnaire was used (refer to Appendix 1 as the basic research instruments). Data collection lasted for 12 days. Primary data collection was entirely cross sectional in that the respondents were available for the first hand information using structured self- administered questionnaire and at the same time observations were being made. This enabled the researcher to gather information faster and at reasonable cost. A structured Self-Administered Questionnaire (SAQ) was directed towards technical staff, supervisors and foremen. It was meant to collect information on the practices of contractors when selecting materials and compacting pavement layers and the resultant effects of repaired cut distresses on road infrastructure, road users and road sector.

3.4 Validity and Reliability of data

The researcher ensured content validity of instruments by conforming to items in the conceptual framework in figure 1 (ref. page). The supervisors evaluated the relevance, wording and clarity of questions or items in the instruments. Reliability of the instruments on the variables was tested via Cronbach Alpha method provided by the Statistical Package for Social Scientists (SPSS). To ensure that respondents had no bias in responding, utmost confidentiality was accorded as explained in the introductory remark of the questionnaire. Furthermore, the questions were designated in a manner that does not depict the identity of the respondent or company.

3.5 Field Tests

A population of 10 roads was used and random samples of four (4) roads were randomly selected. The researcher dealt with cuts across each of the selected roads. The tests were conducted at five (5) repaired utility cuts to establish the structural strength and properties of pavement layers. Samples of materials (soils) were collected from random sample of five (5) repaired utility cuts identified on selected roads in Kigali City with a view to establish moisture content and degree of compaction. The sand replacement method was adopted to obtain the volumes of materials (soils) for testing. Each sample was sealed in separate labeled polythene bags for identification and adequate maintenance of field conditions. Furthermore, in situ field experiments were carried out on each of the five (5) repaired utility cuts to establish the relationship between structural properties and strength of structural pavement layers (Appendix 5). To achieve meaningful California Bearing Ratio (CBR) results, a TRL-Dyanamic Cone Penetrometer (DCP) field-testing machine was used.

Particular attention was paid to the following issues of interest:

1. The vertical holding of the instrument
2. Proper and accurate reading of a standard calibrated steel ruler
3. Uniform raise and drop of standard weight
4. Protection of underground utility facility against destruction by the one cone

3.6 Laboratory test

Samples of materials (soils) delivered to the laboratory were tested for moisture content and degree of compaction. With respect to moisture content, ten (10) tests were run using BS Heavy compaction test to enable distinguishing repaired utility cuts.For the degree of compaction, ten (10) additional samples were subjected to BS Heavy compaction test method (Appendix 5).

3.7 Data analysis and presentation

This section has two sub-sections, one on data processing and the other on (actual) data analysis. Data was coded according to the responses to bring out an essential pattern and this was done to ensure exclusiveness, exhaustiveness and representation. Editing was done to verify the validity of questions before entry. A study database using SPSS software was created. Computerized data editing was performed after data entry to identify missing and inconsistent responses scientifically. Wherever missing, inconsistencies and out of range values were identified and correct data were checked with original questionnaire to remove errors. After cleaning the data, analysis was carried out. Analysis at univariate level was based on relative frequencies (on percentages). Results were presented in form of graphs, pie charts and frequency tables.

CHAPTER FOUR: DATA COLLECTION AND PROCESSING

4.1 Introduction

This chapter presents findings from data collected related to road surface distresses (cracks, depressions, potholes and bleeding) caused by cutting and their variation measured over a three month period. The practices of contractors when selecting materials for repair of cuts and compacting pavement layers (Appendix) and the resultant effects of repaired utility cut distresses on road users, road sector and road pavements were considered. This is in addition to the best practice to reduce repaired cut related distresses on road structural pavements. Data were coded, tallied, percentages calculated and presented in form of tables, pie charts and graphs for descriptive analysis.

4.2 Return Rate from respondents

Findings and interpretation of the results depended on the data collected from the field. However, to substantiate validity and reliability of the results, similar secondary source of information was used to beef up results from the study in form of discussions. Out of the 242 Self-Structured Administered Questionnaires (SAQ) distributed to respondents, the study registered a return of 186 SAQ, which gives 79% response rate (Appendix 2).

4.3 Background information

The findings of the survey revealed that the service providers whose activities affect road structural pavements was as follows: 40% City of Kigali and RTDA, 35% were service utility providers and 15% were contractors while 10% were internet providers as shown in Figure 4.1. The results reveal that City of Kigali, RTDA and utility service providers companies contribute 75% of the cuts that inflict damage to the road pavements.

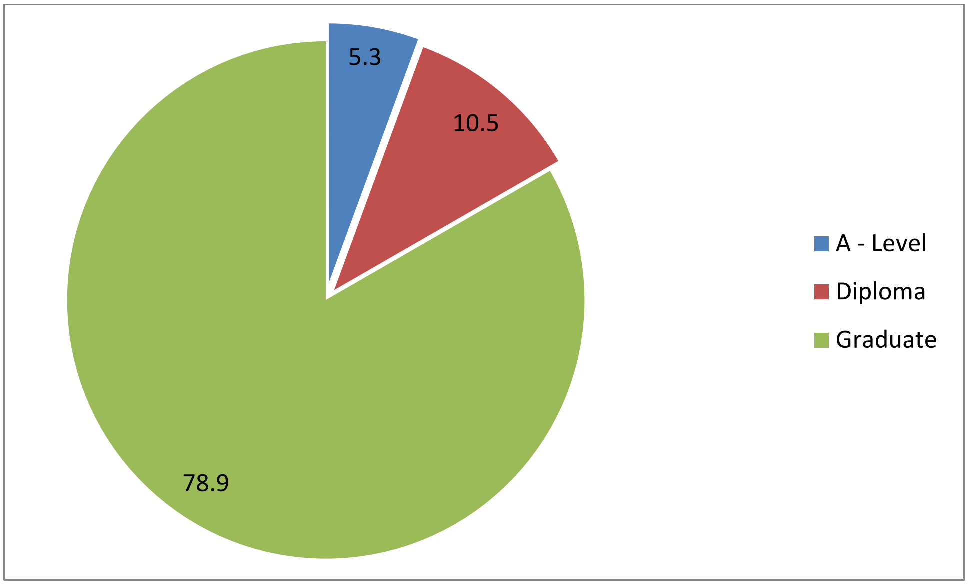


Figure 1: Service providers whose activities affect road structural pavements

4.3.1 Designation at place of work

The results show that 65% of the respondents were ordinary technical staff, 30% were supervisors and 5% others who included artisans and headsmen as shown in Figure 3. Majority of workers employed by the organizations or companies to cut install facilities and repair cuts are ordinary technical staff. Hence, they are qualified to execution the construction work.

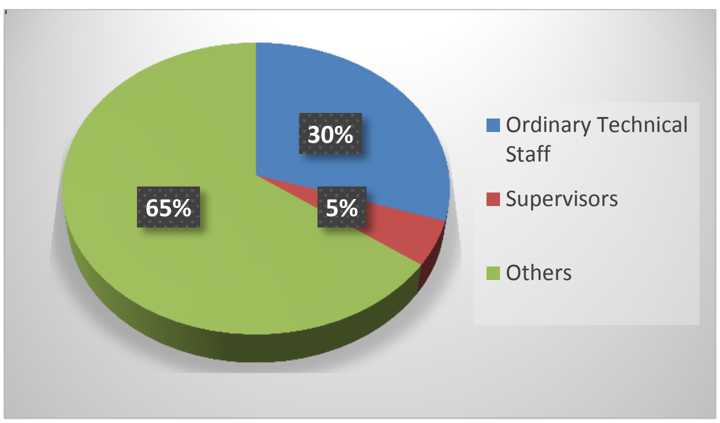


Figure 2: Designation of employees

4.3.2 Highest level of academic qualification

To establish their opinions, the survey results shown in Figure 4 revealed that 78.9% of the respondents were graduates with Master and Bsc degrees, 10.5% were Higher and Ordinary

Diploma holders and 5.3% had completed “A” level, while 5.3% were Advance and Ordinary craft certificate categories.

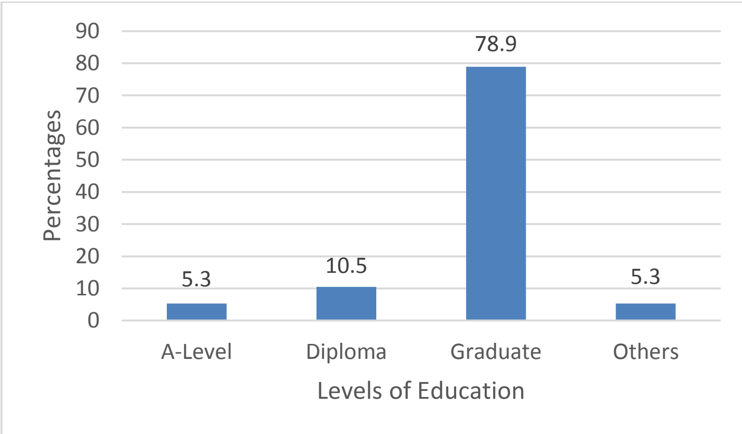


Figure 3: Level of academic qualification

In general, the majority of employees for different organizations or companies are graduates and diploma holders, hence their opinions regarding the study are considered reliable.

CHAPTER FIVE: DATA ANALYSIS AND DISCUSSION OF RESULTS

5.1 Introduction

In this chapter, data were analysed at two levels; descriptive analysis of all the relevant variables as captured in the survey instrument (Appendix 1) and bivariate analysis to determine associations between variables. Furthermore, the results obtained from in situ field density and laboratory tests were observed. Using a TRL Dynamic Cone Penetrometer (DCP) machine, results from California Bearing Ratio (CBR) tests at repaired utility road cuts were formulated.

5.2 Road surface and subsurface distresses due to cuttings

5.2.1 Share of Cuts by Company

The findings were obtained in repaired road cut distresses including surface distresses caused by cutting of road structural pavements. In addition, Appendix 3 shows a map with locations of repaired road cuts on the selected roads in Kigali. A comparative analysis was made to utility service providers to identify those predominantly cut roads for installation of underground facilities. It was noted as shown in Figure 5 that electricity had the highest percentage of cuts on all roads, followed by telecom, water and others respectively.

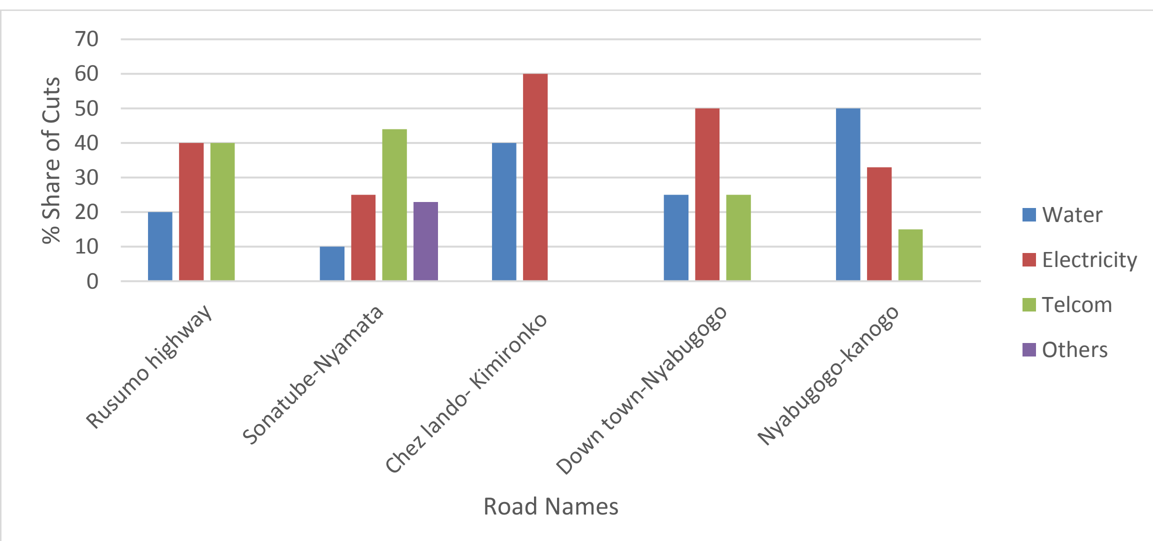


Figure 4: Percentage share of utility cuts by Companies

In view of the above findings, it appears that activities of utility companies extensively inflict damage to road structural pavements, through cutting for installation of underground facilities. The findings with Walaa and Elhussein (1999) who observed that different utility service providers dig and restore utility cuts worldwide to install new services repair or upgrade existing facilities.

5.2.2 Types of distresses and their variations

The study revealed potholes, depressions, cracks and bleeding and their frequencies on the five (5) selected roads in Kigali. It was established that three (3) out of the five repaired roads cuts developed all the four forms of distresses. The general overview established that depressions ranked highest, followed by cracks, bleeding and potholes respectively.

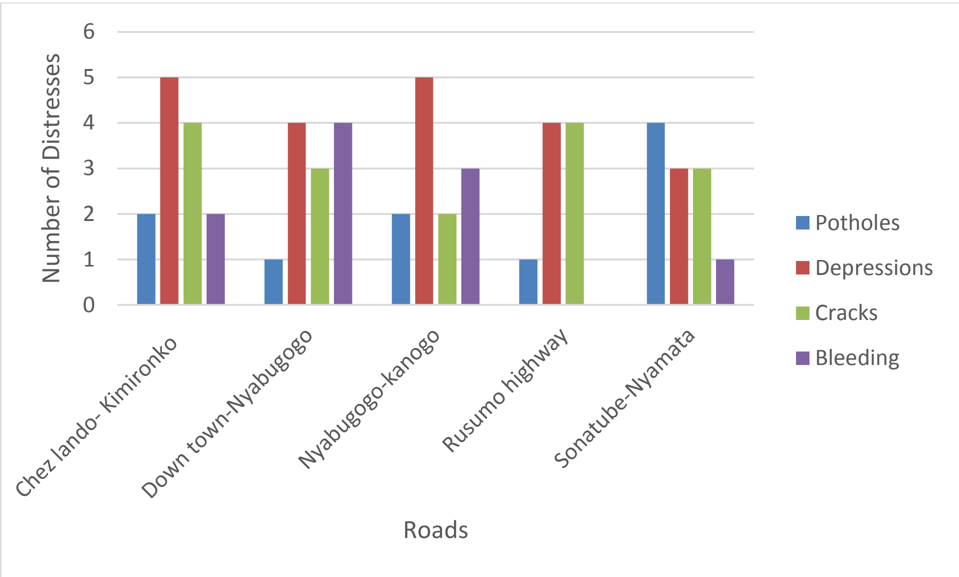


Figure 5: Types of distresses observed on roads in Kigali

5.2.3 Trends of distresses in a 3 month period

Comparisons were made to distresses on repaired utility cuts and those on regular nearby surfaces to establish their dimensional variations overtime.

Depressions

It appears that the rate of progression of depressions over three (3) months period was higher on the utility cut than on the regular surface. This implies that utility cuts are not well repaired and hence fail fairly fast. The findings are in line with Hawii Asphalt Pavement Industry (2003) assentation, that depressions are noticeable when filled with rain water and their variation in settlement result from inadequate compaction during construction.

Cracks

Pattern of interconnected series of cracks were observed on repaired utility cuts and on nearby regular surface. To access the patterned behaviours with time, measurements were made on both surfaces for the area covered a three (3) months period. The area of cracked surface remained fairly constant for regular surface as opposed to the utility cut where cracked area increased from $420mm^2$ to $650mm^2$ (55% increase) over three (3) months period. This implies that the methods/practices applied by contractors during repair on utility do not meet the set standards leading to higher failure rate.

Potholes

To investigate the dimension behavioural change of distresses on utility cuts with time, measurements were taken for width (diameter) of potholes over a three (3) months period. For purposes of comparison, similar measurements were taken on a regular surface in the proximity of the utility cut. The results showed higher rate of progression (7.5 times) on the utility cut compared to regular surface. The finding indicates that utility cuts are not repaired to specific standards by contractors resulting into remarkable failure rate.

Bleeding

To investigate the rate at which bleeding distresses progress on utility cuts with time, measurements were taken to access the extent of area covered over a three (3) months period. To ascertain the difference, measurements were taken on a regular surface in the vicinity of the utility cut. The bleeding features appears low on regular nearby surface compared to utility cut where the trend rose from $300mm^2$ to $420mm^2$ (40% increase) over a three (3) months period. This truly justifies that contractors do not heed to standards applicable to repair cut and thus bleeding features seen appearing on surfaces. Other possible reasons could be when an asphalt binder fills the aggregate voids during hot weather changes overtime and aging of bitumen or poor mix of the constituent materials.

5.3 Current practices on utility cutting across roads

This aspect focused on establishing whether contractors adhere to specific standards when selecting materials for repair of cuts and compacting pavements layers. The researcher used a structured questionnaire together with an observation sheet (Appendix 1). Structural behaviours and properties of pavement layers at repaired cuts were obtained by use of Dynamic Cone Penetrometer (DCP).

5.3.1 Permissions for road cutting

These were investigated to substantiate whether utility service providers apply and secure permits from relevant authorities to cut roads. The objective targeted the trend number of permits issued annually by City of Kigali. The researcher made observations on permits granted according to records to identify roads for which permits were issued. It was found that no records of permits were issued.

5.3.2 Workmanship for materials in pavements layers

A population of 20 roads was used and a sample of six (6) roads randomly selected from the road for which permits were granted for cutting. The researcher dealt with cuts across each of the selected roads. Tests were done on materials to establish the degree of compaction with a view of using these parameters to find out whether contractors adhere to specific standards.

Thickness for pavement layers

The investigations were conducted using Dynamic Cone Penetrometer (DCP) in situ field testing machine on repaired utility cuts. The tests were conducted at ten (10) repaired utility cuts to establish the structural strength and properties of pavement layers. The results of thickness at each repaired utility cuts were compared with the Ugandan and Kenyan design manual standards to establish conformity by contactors when selecting materials and compacting pavement layers.

Road base

Regarding road bases, two (2) out of ten (10) repaired cuts representing 20% satisfied the recommended 125-200mm thickness according to Uganda and Kenya design manuals. While 10% were below the minimum of 125mm and 70% were above the maximum 200mm thickness.

For the sub base, all the ten (10) repaired cuts (100%) ranged between 340-840mm thick compared to 200-300mm range recommended by Uganda design manual.

The finding shows a major indicator of non-conformity to specifications of roads at repaired cuts. Such thickness above standards does not allow the compacting equipment to attain the required strength. In such situations, there are high expectations of distresses, which eventually compromise the intended service lives of roads. The findings agree with Walaa and Elhussein (1999) who argued that the contractors had neither a mechanism of design or construction specification to reduce the effects and noted the absence of sufficient engineering practices as one of the main causes of restoration problems.

Degree of Compaction for pavement layers

To investigate the degree of compaction for road base and sub base, the study focused on establishing whether the repaired road cuts satisfied the required compaction standards. The researcher obtained grab samples of soils from the same repaired utility road cuts in Kigali (Appendix 5). The samples were subjected to compaction laboratory test (BS Heavy Compaction Test). The tests gave results on the degrees of compaction for road base and sub base pavement layers for ten (10) repaired utility cuts at selected roads in Kigali. One (1) out of ten (10) samples representing 10% of the repaired utility cuts was within the recommended standard of 95% Maximum Dry Density (MDD).

The findings indicate that contractors did not properly observe the restoration compaction standards during repairs of cuts and this greatly contribute to distresses on road pavements.

5.3.3 Types of materials for repairing road base

The study sought to investigate the type of materials used for road base by contractors when repairing utility cuts. The types of materials were considered important basing on the geological, climatic and environmental conditions of the area. The materials investigated were naturally or modified gravel crushed stones. It is indicated in Table 8that, 30.64% of the respondents revealed to have used natural or modified gravel, while 25.25% of the respondents stated to have used graded crushed stones and 44.10% used both types of materials.

Table 8: Types of materials used when repairing road cuts

Types of materials	**Number of respondents**	**Percentages**
Natural gravel or modified	57	30.64
Graded crushed stone	47	22.26
Both	84	44.10
Total	**186**	**100**

The above findings are conformity with Uganda road design manual (2005) which stipulates that materials such as natural or modified gravel and graded crushed stones are selected depending on availability, cost, haulage distance and traffic classes.

5.3.4 Cement stabilization

The study investigated the types and percentage or amount of stabilizing materials used for road base. Focus was put on Ordinary Portland Cement, hydrated lime and bituminous binders. The findings revealed that 54.84% respondents use ordinary Portland cement without any addition at 3-4% rate, 34.95% use 3-5% while 10.21% use 3-6%. Table 9 shows the predominantly used stabilizing materials including percentage ratios.

Table 9: Ordinary cement, time to finish and complete compaction, period to protect and cure surfaces

Ordinary cement (%) without any addition	**Number of respondents**	**Percentage**
3-4	102	54.84
3-5	65	34.95
3-6	19	10.21
Total	**186**	**100**
Finishing and completion of compaction using cement		
Less than 2 hours	102	54.84
2 hours	47	25.27
More 2 hours	28	15.05
Not reported	9	4.84
Total	**186**	**100**
Period taken to protect and cure the surfaces when using cement		
less than 4 hours	102	54.84
4 hours	28	15.05
More 4 hours	56	30.11
Grand total	**186**	**100**

The finding revealed that 3-4% ratio of ordinary Portland cement is dominantly used. Uganda design manual (2005) states that cement can be used on a wide range of materials provided it does not exceed 5% to avoid cracking.

Time taken to finish and complete compaction using cement

Time taken to finish and complete compaction was considered influential in stabilizing road bases. The findings showed that 54.84% respondents use less than 2 hours after finishing and completion of compaction of road base, 25.27% use 2 hours, 15% use more than two (2) hours while 4.84% did not respond as shown in Table 9. The research findings agree with completion of compaction requirements of road base as stated by Kenya's Ministry of Transport and Communication (2000) design manual.

Period taken to protect and cure the surfaces

The study revealed that 54.84% of the respondents use less than four (4) hours to protect and cure road base surfaces, 30% use more than four (4) hours while 15% use four (4) hours as shown in Table 9. Uganda's design manual (2005) recommends less than four (4) hours as more appropriate period for protecting and curing road base surfaces.

5.3.5 Lime stabilization

The study also investigated the percentage of lime applied during stabilization of road. The findings showed that 39.78% of respondents use 3-4% of hydrated calcium lime, 30.11% use 4-5% and 25.27% use 4-6% while 4.84% use 5-6%. A 3-4% and 4-5% ratio of hydrated calcium lime is mostly used during repair of road cuts. The 3-4% percentage ratio of hydrated calcium lime is in line with the ratio recommended by Uganda's design manual (2005).

Cure and protection of surfaces

Furthermore, the study showed that 45.16% of the respondents take eight (8) hours to cure and protect surfaces, 39.78% takes less than eight (8) hours while 15.06% take more than eight (8) hours as seen in Table 4.3. The findings conform to the specifications by Uganda design manual (2005).

Time for finishing and completion of compaction of road base using lime

The researcher further investigated the time taken to finish and complete compaction of road bases for repair. This was considered to ascertain whether the duration to finishing and compaction of the road base has implications on using hydrated calcium lime. The findings showed that 60.22% of the respondents take less than four (4) hours, 25.27% take four (4) hours while 14.51% take more than four (4) hours as summarized in Table 10. It was established that less than four (4) hours is the appropriate time to finishing and completing compaction of road base using hydrated calcium lime.

Table 10: Hydrated calcium lime, period taken to finish and complete compaction, cure and protect surfaces

Hydrated calcium lime (%)	Number of Respondents	Percentage (%)
3-4	74	39.78
4-5	56	30.11
4-6	47	25.27
5-6	9	4.84
Total	**186**	**100**
Period taken to finish and complete compaction using lime		
less than 4 hours	112	60.22
4 hours	47	25.27
more than 4 hours	27	14.51
Grand total	**186**	**100**
Period taken to protect and cure the surfaces when using lime		
less than 8 hours	74	39.78
8 hours	84	45.16
more than 8 hours	28	15.06
Total	**186**	**100**

Generally, it appears that 3-5% range is the percentage of hydrated calcium lime commonly used for stabilization the road base. The findings corresponds with the recommendations of Kenya's design manual (2000) and Uganda design manual (2005) which call for hydrated calcium lime as more effective stabilizer on natural or modified gravel materials with PI greater than 10 while quick lime is strongly discouraged due to health risks.

5.3.6 Graded Crushed Materials

Granularity of stones

Graded crushed stones were assessed and occasionally used in repairing utility cuts. Crushed stones were assessed based on the granularity for the different traffic classes in repairing utility cuts as shown in Table 11. The study revealed that 45.16% of the respondents use 0/40mm, 25.27% use 0/30mm and 25.27% use 0/40-0/60mm range while 4.84% did not respond. The findings showed that the majority use 0/40mm granularity size of stones. Kenya design manual design manual (2000) recommends 0/40mm granularity size of stones for provision of stable road base.

Percentage of fines considered for stability of road base

The researcher investigated the amount of fines required in graded crushed stones to establish the percentage distribution that provide a mechanically stable road base. The results in Table 11 showed that 40.32% of the respondents use less than 4% of fines of 0.425 diameter sizes, 39.79% use 4% fines while 19.89% use above 4%. This indicates that most contractors use 4% fines of 0.425mm irrespective of source and climate. However, Kenya design manual (2000) and Uganda design manual (2005) are in contrast. It is stated that selection depends on the source of materials, climatic conditions and environmental concerns.

Table 6: Percentage distribution of granularity of stone (A, B, C) used for traffic classes (T2, T3, T4, T5), percentage of fines considered for stability of road base

Class of granularity of stones (A,B,C) used for traffic classes (T2,T3,T4,T5)	**Number of respondents**	**Percentages**
0/30mm	47	25.27
0/40mm	84	45.16
0/40-0/60mm	46	24.73
none of the above	9	4.84
Grand total	**186**	**100**
Percentage of fines (0.425mm) considered for stability of road base		
less than 4%	75	40.32
4%	74	39.79
above 4%	37	19.89
Total	**186**	**100**

In view of the above findings, 0/40mm granularity and 4% fines (0.425mm) is typically used in repair of cuts for mechanical stabilization of road base. The findings conform to the specification by Kenya road design manual (2000) and Uganda road design manual (2005).

5.3.7 Wearing course materials

Prime coating materials

The study investigated the prime coating materials used by contractors to find out whether the road design manual specifications are observed. The findings showed that 57.53% of the respondents use prime coat for surface dressing of road cuts, while 32.27% use Tack coat and 10.20% others use bituminous emulsions as indicated in Table 12. The study revealed that prime coat materials dominate during repair of cuts for surface dressing.

Type of binders

Furthermore, the study involved evaluating the types of binders predominantly used for priming surfaces. It was revealed that 52.15% of the respondents usemoisture content (MC) 30 while 47.85% use moisture content (MC) 70 binders are predominantly used for surface dressing of road cuts. The findings agree with Kenya road design manual (2000) and Uganda road design manual (2005) recommendations of moisture content (MC) 30 and 70 as appropriate binders for surface dressing.

Table 12: Materials used on surface dressing in repair of utility road cuts:

Type of material	**Number of respondents**	**Percentage**
Prime coat	107	58.53
Tack coat	60	32.27
Others	19	10.20
Total	**186**	**100**
Binders used		
MC 30	97	52.15
MC 70	89	47.85
Others	0	0
Total	**186**	**100**

5.3.8 Considerations for prime coating and speed used to roll over after spreading

Rate of spry for prime coating

The prime coating practice was investigated with a view to establish the rates of spray. The results showed that 65.05% of the respondents use 0.8 – 1.2 litres/m^2 as the rate for spraying prime coat materials for repair of road cuts, 30.10% use 0.5 – 0.79 litres/m^2, while 5% use 1.2 –

2.0 litres/m^2 as summarized in Table 13. It was established that 0.8 – 1.2 litres/m^2 is the commonly used spry rate for prime coating surface for repair of road cuts.

Speed used to roll over after spreading the bituminous concrete

In addition, the speed used to roll over after spreading bituminous concrete was considered to ascertain adherence to the recommended speed. It was found out that 54.85% of the respondents' use 5km/hr speed to roll over after spreading bituminous concrete, 45.16% use less than 5km/hr and none uses more than 5km/hr. The findings are summarized in Table 13.

Table 73: Consideration for rate of spray for prime coating and speed used to roll over after spreading bituminous concrete

Rate of binder spray	**Number of respondents**	**Percentage**
0.5 – 0.79 litres/m	56	30.10
0.8 – 1.2 litres/m	121	65.05
1.21 – 2.0 litres/m	9	4.85
Total	**186**	**100**
Speed used to roll over after spreading the bituminous concrete		
less than 5km/hr	84	45.16
5km/hr	102	54.84
more than 5km/hr	none	0
Total	**186**	**100**

It was confirmed that 0.8 – 1.2 litres/m^2 is typical rate for prime coating. The findings agree with Kenya road design manual (2000) recommendation. The findings also are in agreement with the recommendations of Gurchan*et al* (2004), Kenya road design manual (2000).

5.3.9 Wearing course thickness for different traffic levels

Bituminous mix and surface dressing

The study established surface dressing and bituminous mix wearing courses including their thickness in relation to traffic levels. Thickness of wearing course at repaired cut bearing potholes were compared to the nature of traffic levels and the recommendations as shown in Table 14. The study revealed that 51.4% of roads ranged between 50 – 80mm thicknesses for light heavy traffic level, 25.7% were less than 50mm for light traffic level and 22.9% ranged between 80 – 100mm for heavy traffic category, and none was registered for thickness grater then 100mm. The findings showed that majority of roads belonged to light heavy traffic level category whose thickness ranged between 50 – 80mm as summarized in Table 14.

Table 8: Thickness of wearing course for different traffic levels

Traffic levels	**Wearing course thickness (mm)**	**Number of roads**	**Percentage (%)**
Light	<50	9	25.7
Light heavy	50-80	18	51.4
Heavy	80-100	8	22.9
Very heavy	>100	0	0
Total		**35**	**100**

This result show that most roads in Kigali were light heavily trafficked and the wearing course thickness ranged between 50 – 80mm and less than 50mm belonging to light traffic level.

5.4 Effects of repaired utility cut distresses on roads, road users and the road sector

The aspect such as costs of maintenance, road lives and traffic jam were investigated.

5.4.1 Increased costs of maintenance

Increased costs of maintenance to road sector resulting from cutting, digging and installation of facilities by utility service providers on road structural pavements and the distresses that accrue after repair by contractors was studied. To achieve the objective, data on costs of maintenance were obtained from Broadband System Corporation (BSC) budgetary expenditure during laying the Fibber. The total expenses were forty million dollars (40m $).

The study shows that the road sectors incur increased costs of maintenance resulting from the activities of service providers although the researcher did not have official data. The study findings agree with Walaa and Elhussein (1999) who showed that distresses lead to increase costs to road sectors due to unsatisfactory restoration performance. Jones (1999) also cited costs associated with utility works as direct, indirect and social.

5.4.2 Road life span

Road lifespan at utility cut was investigated at five (5) in Kigali to establish whether activities of service providers affect road structural pavements. Twelve (12) repaired utility cuts were studied. 80% of the repaired cuts had depressions and cracks respectively as shown in Table 15. Walaa and Elhussein (1999) pointed out that cutting of road progressively affects its structural integrity and performance. Bodocsi et al (1995) and Tie Water (1997) are in agreement with the above.

Table 9: Repaired utility road cuts and forms of distresses at five roads

Name of road	N^o of road cuts	Percentages (%)	Form of distresses observed
Rusumo high way	3	30	Depressions, cracks
Town centre Nyabugogo	2	20	Depressions, cracks
Town centre Kanogo	2	20	Depressions
KimironkoAmahoro stadium	2	20	Depressions, cracks
Sonatube-Nyamata	1	10	Depressions, cracks along the edges of cut
Total	**10**	**100**	

5.4.3 Traffic jam

The study investigated the effects of distresses with the view to establish whether they cause unnecessary traffic jam to road users. A pothole was identified purposively at a repaired utility cut. A sample of twenty five (25) vehicles irrespective of their length, sizes or axle load were tested considering the time wasted at pothole. Time taken by each vehicle was recorded using a stop clock and an average of 154.81 seconds (2.58 minutes) was taken by vehicles at this pothole as seen in Figure 7.

Vehicles Vs Time

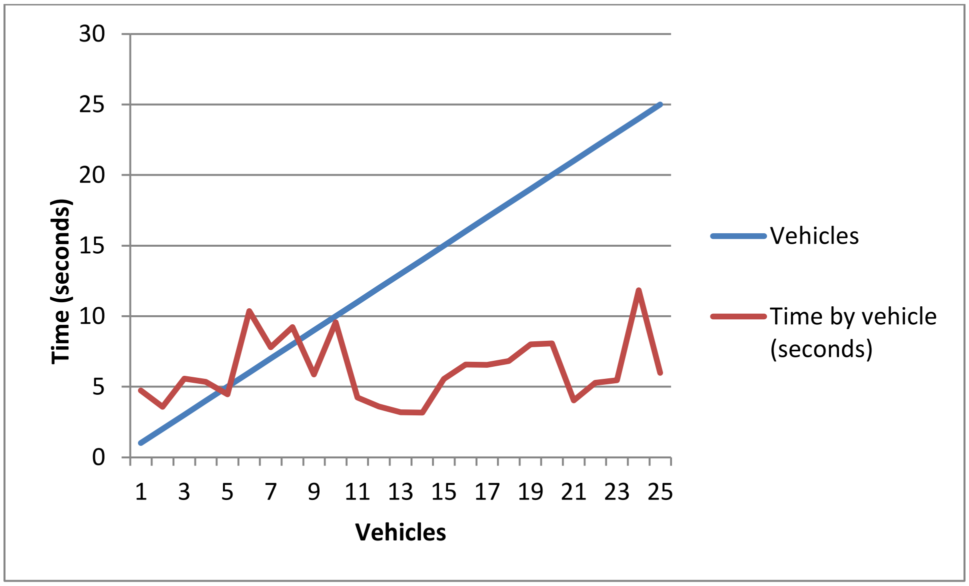


Figure 7: Variations in time taken by vehicles at a pothole

The findings reveal variation in time taken by vehicles to overcome either potholes or depressions as demonstrated by the delay and reduction in travel speed and time. This consequently led into queues of vehicles at the spot causing unnecessary traffic jams to road users. In 2013 between August to November, at SonatubeRwandex road where there is utility cuts lasted for about three months without being repaired properly caused unnecessary traffic jam. In summary, it was asserted that utility cut distresses lead to increase costs of maintenance to the road authority, reduction in roadway service lives and unnecessary traffic jam to road users.

5.5Best practices to reduce repaired utility road cut distresses

An investigation was made into the best methods/practices to reduce utility cut distresses on road structural pavements with a view to overturn the impending reduction in the performance of road infrastructure by the activities of service providers in Rwanda. A self-administered questionnaire was used (Appendix – 1). The findings revealed that 47.85% of the respondents supported trenchless technology as the best practice to reduce utility cut distresses, 27.96% suggested structural design approach based on sound engineering fundamentals and 11.83% opted for co-ordination among the utility companies and road users. Furthermore, 8.06% preferred open-cut and restore technique while 4.3% suggested introduction of ducts, core boring, proper planning and use of trained, qualified and competent staff as summarized in Figure 8.

Best practices to reduce distresses

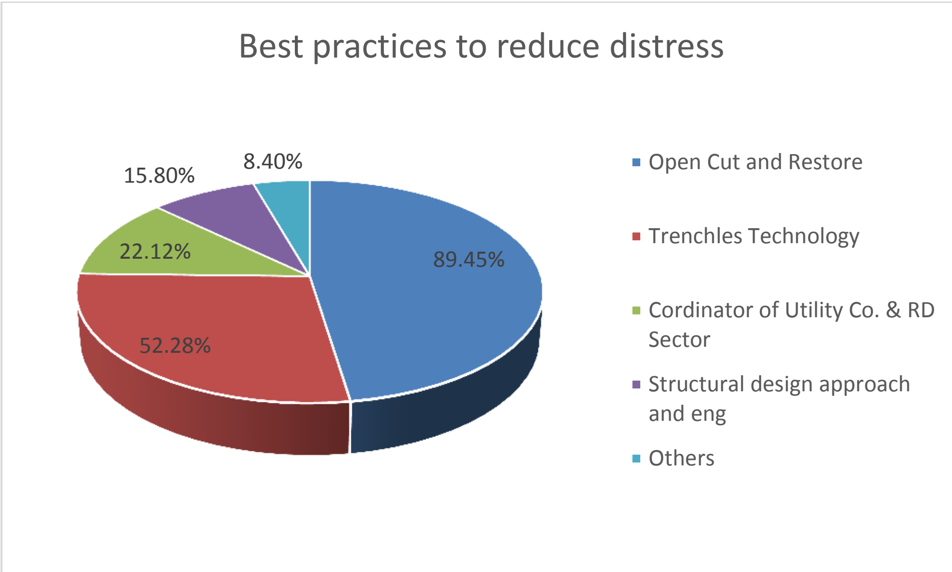


Figure 6: Best practices/methods to reduce repaired utility cut distresses

It appeared that according to respondents best practices/methods to reduce utility road cut distresses on road structural pavements were trenchless technology and structural design approach based on sound engineering fundamentals. This concurs with Jones (1999) who advocated for trenchless technology because of minimum disturbance to traffic, low impact to environment and least inconveniences to the public. Further, Trevor et al (2006) argued that the methods reduce damage, costs and reduction in accidents. However, the costs involved in implementing the practices/method may hinder the progression of the proposals and hence a need to evaluate the cost and other subsequent implications.

5.6 Summary of findings

5.6.1 Research question one: Types of utility cuts distresses and their variation over time

In this study which was based on 29 repaired utility cuts identified on five (5) roads in Kigali, the distresses that were significant included potholes, cracks, depressions and bleeding. These were observed from completion of re-instatement of roads cut and repaired by utility service providers to access their progression.

With regard to depressions, a gradual variation in depth was 56mm on utility cuts as opposed to 16mm on regular surface over a three months period. The study revealed continuous settlement over time, which later stabilizes due to repeated traffic loading, stagnant rainwater and consolidation of un-compacted pavement layers. This however, does not leave the surface level. The DCP-CBR relationship results revealed premature failure due to inadequate selection of materials and compaction of pavement layers by contractors. The field and density results revealed that only 20% satisfied the degree of compaction standards. Regarding potholes, five (5) out of twenty nine (29) repaired road cuts representing 17.2% had developed potholes and the diameter was higher (7.5 times) on the utility cut compared to regular surface. Most potholes were sighted in roads with wearing course thicknesses below 50mm and bituminous concrete in the range of 50-80mm. The results revealed that roads with (50-80mm) wearing course thickness severely suffer surface distresses. Stagnant storm water (poor surface drainage) also weakens road structural pavements layers that further worsened the repeated traffic loading negative effect. Therefore, the causes of premature failure are multiple and mutual in nature resulting from non-conformity to specific designed standards. In the case of cracks, these were described as patterns of interconnected series of cracks that exhibited at edges of cuts, between the existing and reinstated wearing courses. The cracked surface area for regular surface remained constant while on utility cut increased from $420mm^2$ to $650mm^2$ over a three (3) months period. It appears that cracks result from poor selection of materials and compaction of pavement layers. Referring to depressions, progression of depth shot from 7mm to 63mm on the utility cut than on the regular surface over the three months (3) period. It may be proposed that depression result from poor installation practices by contractors. For bleeding, 44.8% repaired utility cuts exhibited bleeding at the edges and the entire stretch of the repaired utility cut. Bleeding features on regular nearby surface increased from $300mm^2$ to $400mm^2$ (40% increase) over a three (3) months period. The study established that bleeding is irreversible whether during cold weather or at low loading, as it continuously accumulates at paved surface over time especially during hot seasons. It further noted that bleeding results from poor mix design of bitumen and low air voids content in asphalt concrete.

5.6.2 Research question two: Practices of contractors for repair road cuts

Energy, water and sanitation (EWSA); MTN; Rwandatel and RDB had applied permission for road cuts. This substantiates that their activities inflict damage to road infrastructure. The subsequent effects are reduction in service life span, increased maintenance cost and unnecessary traffic jams.

The results showed variations in pavement strength of soils and crushed stone at repaired utility cuts represented by penetration rates (slopes) and BCR variations in thickness of pavement layers. The revelation showed substandard selection of materials and compaction of road structural pavement layers. This was confirmed by the rate of penetration (slopes) that reflect variations in the pavement structural strength and properties that manifest inadequate compaction methods and materials selection by contractors described weak subgrade strength. Therefore, standards should be enforced for penetration of road structural pavements from distresses especially at repaired utility road cuts.

Regarding compaction, one (1) out ten (10) samples (10%) at the repaired utility road cuts conformed to the recommended 95% MDD degree of compaction. Therefore, failures relate to non-compliancy to selection of type of material and method of compaction, type of compacting equipment and type of construction soils during reinstatement of utility cuts. Forty five percent point sixteen (45.16%) of the respondents recommended natural or modified and stone crushed aggregates. The study showed that selection depends mainly on the economic availability of materials, environmental and climatic changes especially in tropical areas, traffic levels based on Annual Daily Traffic (ADT) for design purposes and the intended design service life.

Referring to the results, lime (3-4%) and cement (3-4%) are predominantly used. However, variations were noted in the methods and amount of application. Less than four (4) hours is the recommended duration for protection and curing of surface and less than two (2) hours is allowable time for finishing and completing compaction using cement followed by seven (7) allowable days for permitting traffic to surfaces while less than eight (8) hours and four (4) hours are typical respectively for lime.

Prime and Tack coat are use depending on depth of penetration rated at 3-4mm, quantity of spray limited to two (2) days of dry surface, low viscosity, applied when hot and its application also depends on the texture and density of surface. While spray rate range between 0.8 - 1.2litres/m^2 considering the type of stone chippings, surface and the climatic condition at the time of application.

Light-medium-heavy traffic category with 50-80mm thickness dominated surface dressing and bituminous concrete mix but less than 50mm wearing course thickness was more susceptible to potholes. Regarding granularity and percent fines, the study confirmed a combination of 0/40 and 0/30mm class with a minimum of 4% as appropriate to minimize segregation and achieving maximum impermeable layer compatible with good compaction and high traffic. In addition, proper particle size distribution of crushed stone produces mechanical dense firm foundations for pavement layers.

5.6.3 Research question three: Resultant effects to road users, road sectors and road infrastructure.

To access the effects of utility cut installation to various stakeholders, the study made use of field observations, qualitative and descriptive method to analyze the effects to adopt the outcome. The following were found out to be the effects of utility cut distresses:

- Reduction in service life to road infrastructure;
- Increased maintenance costs to road sectors;
- Unnecessary traffic jams during and after installation of facilities.

It was figured out that utility service activity and practices by contractors have greatly contributed to the surface and sub-surface distresses. It is upon road sectors and utility companies to use the findings to improve on the underground installation methods of facilities. In addition, to adopting better remedial measures against cuts and excavations on road structural pavements that inflict damage.

5.6.4 Research question four: Best practices to reduce utility cut distresses.

Analysis of the data collected has revealed that the following are the practices/methods applied to reduce distresses due to utility cuts:

- Trenchless technology/core boring;
- Structural design approach based on sound engineering fundamental;
- Co-ordination among utility companies and road sectors (MININFRA, RTDA and City of Kigali);
- Open-cut and restore technique;
- Introduction of ducts;
- Forward planning;
- Training and employ qualified and competent staff for repair of utility cuts on road structural pavements.

Jones (1999) supports trenchless technology method due to minimum disturbance to traffic, low impact to environment and least inconveniences to the public. Trevor et al(2006) gives a similar recommendation based on reduction of damage, costs and few accidents. Jones (1999), supports structural design approach based on sound engineering fundamentals and reliability of construction specifications including field control and use of construction equipment. Open-cut and restore techniques ranked fourth due to citations pointed out by Jones (1999) and Trevor et al (2006). Other recommended introduction of ducts, core boring, government's intervention in formulating by-laws, policies and guidelines and staff training as pointed out by Walaa and Elhussein (1999).

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This study was undertaken to evaluate the damage inflicted on road structural pavements by the activities of utility service providers in Kigali in order to reduce road cuttings. This was achieved by identifying, measuring and observing different types of distresses developed on repaired utility road cuts, which were found varying in size overtime. The non-compliancy to set standards by contractors in selection of material and compaction was confirmed by DCP-CBR tests, a questionnaire survey and laboratory tests on samples of compacted soils. The study also investigate the resultant effects on road cutting with the view of recommending mitigation measures for installing underground utility facilities.

6.2 Conclusions

Basing on the findings from this study, the following conclusions can be made:

I. Surface and subsurface distresses occur in form of cracks, depressions, potholes and bleeding at repaired utility cuts. Variations in depth and width overtime were observed in potholes and depressions. Interconnected patterns of cracks are related to potholes however, their measurement varied in area. Bleeding featured spreading either at the edges or at the entire repaired cut or both. In conclusion, all utility cuts repaired had at least one of the four distresses resulting from the activities of utility service provision;

II. Naturally occurring gravel and stone crushed materials dominated road base structural pavement repair materials. However, roads continue to perform poorly due to non-compliancy with the set standards with respect to compaction, thickness and dry densities as specified in road design manuals. Bituminous/asphalt concrete or surface dressing of 50-80mm thickness wearing course prevailed. However, potholes were predominantly found in 50mm thick wearing course. This confirms laxities in conforming to standards during selection of materials and compaction of pavement layers in repair of utility cuts;

III. The effects of repaired utility cut distresses on road users, road sector and road pavements were found out to be reduction of service life, increased maintenance costs and unnecessary traffic jam;

IV. Trenchless technology, structural design approach based on sound engineering fundamental, co-ordination among utility companies and road sectors, open-cut and restoration technique, introduction of ducts at intervals, core boring, proper planning and finally training and employing qualified competent staff for repair of utility cuts on road structural pavements are in the order as the best remedial measures for utility crossing on roads.

6.3 Recommendations

This study recommends that:

I. Road authorities should always involve utility service provision companies during preliminary, design and implementation works/stages for road construction projects to accommodate all utility components;

II. There is need for proper planning, communication, co-operation and co-ordination of installation activities among utility service companies to prevent common spot cutting on road infrastructure and destruction of underground utility facilities for the different companies;

III. Adoption of new technological and innovation techniques such as core borings and trenchless methods for installation facilities to diminish damage to road structural pavements and destruction of underground facilities among utility companies is needed;

IV. Introduction of ducts or conduits during construction of roads at calculated intervals as demand of utility services and location may determine is paramount. Such facilities can be sub leased to investors and this reduces the cost, time and capital of investment;

V. The need to enhance continuous supervision of contractors by road sector to ensure that specific standards are adhered to during installation and re-statement of utility cuts;

VI. Governments through inter-ministerial sectors and departments should formulate collective guidelines, policies, standards and specifications regarding installation of underground facilities at regional level;

VI. Introduction of standardized road and drainage design manuals for repair of utility cuts on road structural pavements to be encouraged;

VII. Training in skills related to installation and repair of utility cuts, employing technical staff with adequate qualification and experience to revamp the practices of contractors should be encouraged.

6.4 Areas of further research

In the view of the findings from this study, further research is proposed in the following areas to streamline the practice of installing of utility facilities:

I. Explore the suitability of core boring excavation method for installation of underground facilities in Kigali;
II. Evaluation of impact of road drainage on the utility cut workability;
III. Evaluate the involvement of utility companies in implementing road projects in Rwanda.

REFERENCES:

Active Web Corporation (2010). Factsheet N^{o}. 4 Road Drainage; Land Improvement Contractors of Ontario www.drainage.org (19.08-2010) Copy right (1998-1999);

ADC Telecommunications (2007), Performance effects of single mode fibre optic connector, Endface workmanship. www.adckrone.com;

Allan, H. (2007). Construction; maximizing pavement repair; published by interaction media group;

Alexander M. Vaysburd, J. and Carino, B. B. (1999), Report on Predicting the performance of concrete material, 26th and 27th April, 1999;

Amin, M. K. (2005). Social science research: Conception methodology and analysis. Makerere University, Kampala Printery;

Arnold and Itkin, L.L.P. (2008), Poor workmanship in construction;

Best, W. and Kahn, J. (1993). Research in education 7th edition, Allya and Bacon Singapore;

Bodocsi, A. P. D. Pant, A. E, Aktan and Arudi, R. S. (1995); Impact of utility cuts on performance of street pavements-final report, Cincinnati, OH; The Cincinnati Infrastructure Institute, Department of Civil and Environmental Engineering, University of Cincinnati;

BS 1377-4 (1990): Methods of test for Soils for civil engineering purposes – part 4: Compaction-related tests;

CLG research data base (2003): Communities and Local Government; Estimation of actual air tightness based on design and workman assessment;

Collins Essential English Dictionary, 2nd edition 2006, Harper Collins publishers;

Creswell, John. W. (2003): Research design, qualitative, quantitative and mixed approach; 2nd edition, London sage publications thousand Oaks;

Cronbach (1946): Response sets and tests validity; Education and Psychological Measurement, Vol.16 Page 475-494;

Croney, D. Failure Criteria for flexible pavements; Proceedings third international conference on structural design of asphalt pavements, University of Michigan, 1972;

Crowthorne and Berkshire (1993): A guide to the structural design of Bitumen surfaced roads in Tropical and Sub-topical Countries; Overseas Development Administration; 4th edition; overseas centre;

Department of Public Works (1998): The impact of excavation on San Francisco streets. Department of Public Works, City and County of San Francisco and Blue Ribbon Panel on Pavement Damage;

Gurcharan, S and Jagdish, S (2004): Highway engineering, 5th edition published by Jain, A, K;

Hawii asphalt pavement industry (2003): Hapi asphalt pavement guide;

Iowa State University (2005): Proceedings of the 2005 mid-continent transportation Research Symposium;

Jensen, K. Suleiman, M and White, D. J. (2005): Utility repair techniques, Investigation of improved utility cuts repairs techniques to reduce settlement in repaired areas: Final report. Iowa. Dot Project: Center for Transportation Research and Education, Iowa State University;

Jones, C. J. F. P (1999). Policy, Incentives and Barriers to the use of Trench less Technology, in life extension technologies workshop, New York City, August 25-26, USA;

Krejcie, M. (1970). Determining sample size for Research: Journal article: Educational and Psychological measurement, pp 607-610;

Merriam, W (2008). Online dictionary 2008: Infrastructure Merriam-Webster online. http:/www.merriam-webster.com/dictionary/infrastructure, 23rd June 2008;

Ministry of Transport and Communication, Republic of Kenya (2000), Road design manual: Materials and Pavement Design for New Roads, Part III;

Ministry of Works, Housing and Communication, Republic of Uganda (July 2005): Road Design Manual, Vol.3: Pavement Design, Part I: Flexible Pavement;

Michael, P (2009). What is the Contractor: Wise Geek; Conjecture Corporation. Overseas Centre, Transport Research Laboratory;

Mukwaya, I. P. (2004). The challenge of managing urban areas in global environment, Conference at the University of Illinois, Chicago USA 22nd – 24th July 2004;

Proffitt, A. T (1987).Trench Excavation and Reinstatement in New Zealand, National Roads Board New Zealand, Road Research Unit Occasional Paper;

Punmia, B. C. Ashok, K. J. Arun, K. J (2005). Soil Mechanics and Foundation, 16th Edition, Laxmi Publications (P) Ltd, New Delhi Boston, USA;

Rational road drainage design for unbound pavement: Outputs, 1 rational drainage of road pavements PR/INT/244/2002 www.transport/links.org/../projects_v.asp?..road+drainage…pavements (02-03-2010);

The American Heritage (2003): Dictionary of the English language 4th edition, published by Houghton Mifflin Company;

The New Zealand Utilities Advisory Group (2003). Road share: Efficient and accessible loading and utility services are vital for New Zealand to maintain its high standard of living and continued economic growth. November 2003, www.nzuag.org.nz;

TieWater, P (1997). Soil Engineering; 4th Edition, New York; How to reduce utility trenching costs; Better roads; Harper and Row Publishers, April 1997, pp 18-20;

Wilson, T. P. Smith, K. L and Romine, A. R (1999): Manual and Procedures for Rapid Repair of Partial-Depth Spalls in Concrete Pavements;

Transport Research Laboratory: A guide to the structural design of bitumen-surfaced roads in Tropical Countries; Overseas Road Note 31 (1993) 4th Edition;

Trevor, M. Minister of Economic Development and David Parker Minister, Hon. Annette King, Minister (2006): Improving utilities access to road and rail corridors Ministers of Transport, Economic Development and Energy media statement;

Uganda National Road Authority (2009), Report on National Road Construction and Maintenance Programme, Revised Zero Draft. A paper presented at a Joint Transport Sector Review on 20 – 22 October 2009 by Eng. Peter W. Sebanakiita;

Uganda National Road Authority, Status Report on Road Development and Maintenance Programme, January 2010;

Walaa, E. I and Elhussein, H. M (1999): Managing utility cuts; issues and considerations Institute for Research in Construction, National Research Council Canada 1500 Montreal road, Ottawa, Canada KIA 0R6;

Wehmeier, S. (2000): Oxford Advanced Leaners Dictionary.

APPENDICES

APPENDIX – 1

Sample of the Questionnaire

SELF ADMINISTERED QUESTIONNAIRE FOR UTILITY SERVICE PROVIDERS (TECHNICAL STAFF) AND SUPERVISORS OF THE ROAD SECTOR IN KIGALI KIGALI CITY - RWANDA

September 10th, 2013

Dear Sir/Madam

I am carrying out a study on activities of service providers and their effects onto road structural pavements. This study is purely academic and it is anticipated that it will provide recommendations on how best service providers can carry out their activities with minimum effects on the road structural pavements.

The following questionnaire is for Technical staff and supervisors like you. You have been randomly selected to participate in this research by completing the questionnaire. It will be helpful if you assist by answering the questions as per the instructions at the beginning of each section. You are requested to provide the most appropriate answer in your opinion. Your response will be treated with maximum confidentiality it deserves. In any case the questionnaire is anonymous. Please endeavor to fill the questionnaire within two weeks and return to the data collector in your offices.

Yours faithfully,

BONISHULI Clay

Researcher

SECTION A: BACKGROUND INFORMATION

You are requested individually to complete the study questions by selecting the most appropriate answers provided and also supplementing where need be.

N.B: All answers are correct.

1. Organization/Company ………………………………………………………………….

2. Services providers

   Contractors ☐

   Rwanda Transportation Development Agency ☐

   City of Kigali ☐

   Utility Service provider ☐

   Other Specify ☐

3. Your Title/designation at the place of work

   Technical staff (Ordinary) ☐

   Technical staff (Supervisors) ☐

   Casual labourer ☐

   Other specify ☐

4. Highest level of academic qualification attained

   i) O – Level ☐ ii) A – Level ☐

   iii) Diploma ☐ iv) Graduate ☐

   v) Others ☐ vi) No qualification ☐

5. Tick the activities you carry out that affect road structural pavements

   i) Increase of network's capacity and provision of new pipelines or ducts ☐

   ii) Replacement/rehabilitation of defective/existing pipelines ☐

   iii) Extension or improvement of storm water pipes ☐

SECTION B

Practices of contractors when selecting materials and compacting road cut surfaces

B) Road base

6. What are the types of materials used when repairing road cuts road bases?

   i) Natural or modified gravel ☐

☐

ii) Graded crushed stone

iii) Both

Natural or modified gravel

7. What percentage range of stabilization do you consider for the following?

a) For ordinary cement without any addition

i) 3-4%

ii) 3-5%

iii) 3-6%

iv) Above 6%

b) For hydrated calcium lime

i) 3-4%

ii) 4-5%

iii) 4-6%

iv) 5-6%

iv) Above 6%

8. How long do you take to finish and complete compaction using the following?

a) Cement

i) Less than 2 hours

ii) 2 hours

iii) More 2 hours

b) Lime

i) Less than 4 hours

ii) 4 hours

iii) More than 4 hours

9. How long do you take to protect and cure the surfaces when you use the following?

a) Lime

i) Less than 8 hours

ii) 8 hours

iii) More than 8 hours

b) Cement

i) Less than 4 hours

ii) 4 hours

iii) More than 4 hours

Graded crushed materials

10. What class of granularity of stones do you consider for the different traffic?

(The traffic classes are T2, T3, T4 and T5)

i) 0/30mm

ii) 0/40mm

iii) 0/40mm-0/60mm

iv) None of the above

11. What percentage of fines of 0.425mm do you consider for stability of road base?

i) Less than 4%

ii) 4%

iii) More than 4%

12. After cutting the road infrastructure, do you carry out repair?

Yes

No

13. If yes, what materials do you use for repair of road cuts?

a) Surface dressing

i) Prime coat

ii) Tack coat

iii) None

iv) Others

b) Types of binders used

i) MC 30

ii) MC 70

iii) Others specify

c) Rate of spray for prime coating materials (binders)

i) Between 0.8-1.2 litres/m^2

ii) 0.5-0.79 litres/m^2

iii) 1.2-2.0 litres/m^2

iv) Others specify

v) Not necessary

d) What speed do you use to roll over after spreading the bituminous concrete layer?

i) 5 km/hr ☐

ii) Less than 5 km/hr ☐

iii) More than 5 km/hr ☐

OBSERVATION SHEET

14. What are the types of road distresses resulting from road cuttings by utility service providers and what is their variation in measurement (mm) in a three months period on the different roads in Kigali

Name of road									
Variations (mm) over a 3 months' period									
Company	**Chainage**	**Distress**	**1st Day**	**1st 2wks**	**2nd 2wks**	**3rd 2wks**	**4th 2wks**	**5th 2wks**	**6th 2wks**
EWSA		Crack Depressions Bleeding Pothole							
BSC		Crack Depressions Bleeding Pothole							
MTN		Crack Depressions Bleeding Pothole							
Rwandatel		Crack Depressions Bleeding Pothole							
RDB		Crack Depressions Bleeding Pothole							
Others		Crack Depressions Bleeding Pothole							

SECTION C

Best practices to reduce repaired utility road cut distresses on road structural pavements

15. Select best practices/methods that can be adopted to reduce repaired distresses on road structural pavements in Rwanda

i) Open cut and restores technique ☐

ii) Trenchless technology ☐

iii) Co-ordination among utility companies and road sectors ☐

iv) Structural design approach based on sound engineering fundamentals ☐

v) Specify other:

……………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
…………………………………………………………………………………………………..
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
…………………………………………………………………

APPENDIX – 2

Results of the Questionnaire Survey

Analysis of Responses from Organisation/Companies

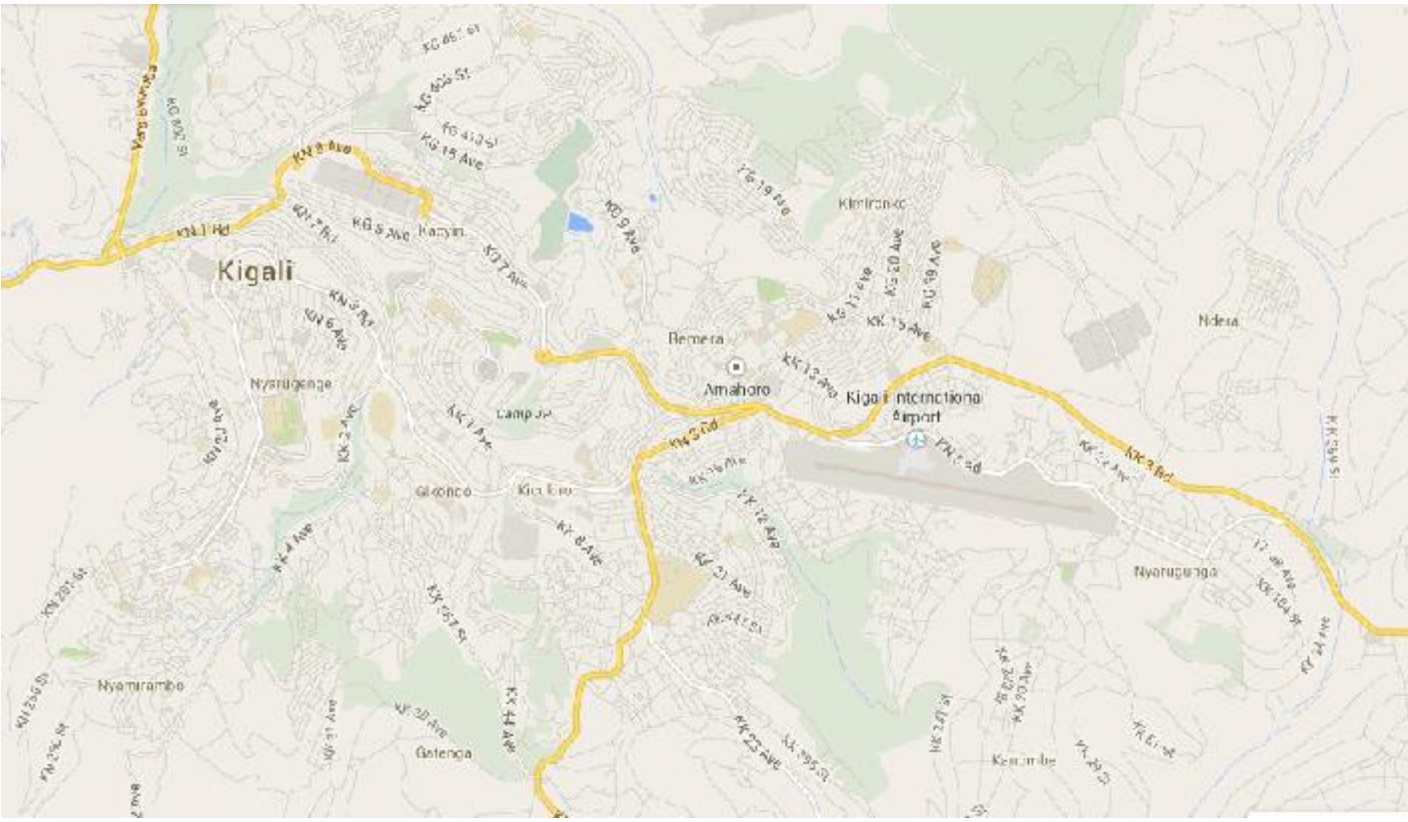
Item	**Response**	**Frequency**	**Percentages (%)**
Nature of Service	Contractor	28	15.05
	Road Authority	74	39.79
	Service Providers	65	34.94
	Others	19	10.2
	Total	**186**	**100**
Tittle/Designation	Technical Staff	121	65.06
	Supervisors	56	30.01
	Others	9	4.93
	Total	**186**	**100**
Highest level of academic qualification	A-level	9	5.3
	Diploma	19	10.5
	Graduate	149	78.9
	Others	9	5.3
	Total	**186**	**100**
Activities that affect road infrastructures	Increase of networks capacity and provision of new or pipelines or ducts	103	55.38
	Replacement/rehabilitation of defective/existing pipelines	46	24.73
	Extension or improvement of storm water pipes	37	19.89
	Total	**186**	**100**
Practices of contractors when pavement materials for repair of road cut			
Material used for repair of dressing	Prime coat	107	57.53
	Tack coat	60	32.26
	Others	19	10.21
	Total	**186**	**100**
Binders used	MC 30	97	52.15
	MC 70	89	47.85
	Others	0	0
	Total	**186**	**100**

Types of binder used	Low Viscosity bituminous binder	158	84.95
	Others	28	15.05
	Total	**186**	**100**
Rate of spray for prime coating materials			
Binders	0.5 – 0.79 litres/m	56	30.11
	0.8 – 1.2 litres/m	121	65.05
	1.21 – 2.0 litres/m	9	4.84
	Total	**186**	**100**
Speed used to roll over after spreading the bituminous concrete			
Speed used to roll over	Less than 5 km/hr	84	45.16
	5 km/hr	102	54.84
	More than 5 km/hr	None	0
	Total	**186**	**100**
Road base			
Types of materials used when repairing road cuts road bases	Natural gravel or modified	57	30.0
	Graded crushed stone	47	25.0
	Both	84	45.0
	Total	**186**	**100**
Natural gravel or modified			
Percentage considered for hydrated calcium hydroxide	3 – 4%	102	54.84
	3 – 5%	65	39.95
	3 – 6%	19	10.21
	Total	**186**	**100**
Percentage considered for hydrated calcium hydroxide	3 – 4%	74	39.79
	4 – 5%	56	30.10
	4 – 6%	47	25.27
	5 – 6%	9	4.84
	Total	**186**	**100**
Time taken to finish and complete compaction			
Using cement	Less than 2 hours	102	54.84
	2 hours	47	25.27
	More than 2 hours	28	15.05
	Not reported	9	4.84
	Total	**186**	**100**

Using cement	Less than 4 hours	112	60.02
	4 hours	47	25.27
	More than 4 hours	27	14.51
	Total	**186**	**100**
Period taken to protect and cure the surfaces when using cement			
Using lime	Less than 8 hours	74	39.79
	8 hours	84	45.16
	More 8 hours	28	15.05
	Total	**186**	**100**
Using cement	Less than 4 hours	102	54.84
	4 hours	28	15.05
	More than 4 hours	56	30.11
	Total	**186**	**100**
Classes of granularity of stones (A, B, C) used for traffic classes	0/30 mm	47	25.27
	0/40 mm	84	45.16
	0/40 – 0/60 mm	46	24.73
(T2, T3, T4, T5)	None of the above	9	4.84
	Total	**186**	**100**
Percentage of fines 0.425m considered for stability of road base	Less than 4%	75	40.32
	4%	74	39.79
	Above 4%	37	19.89
	Total	**186**	**100**
Best practices to reduce repaired utility road cut distresses on road structural pavements			
Best practices/methods to reduce repaired utility cut distresses on road structural pavements	Open cut and restore	15	8.06
	Trenchless technology	89	47.85
	Co-ordination among utility companies and road sector	22	11.83
	Structural design based on sound engineering fundamentals	52	27.96
	Others	8	4.30
	Total	**186**	**100**

APPENDIX – 3

A map showing City of Kigali main roads



APPENDIX – 4

Time taken by vehicles manoeuvring out of potholes

Vehicles	Time by vehicle (seconds)	Cumulative time (seconds)
1	4.73	4.73
2	3.57	8.3
3	5.58	13.88
4	5.34	19.22
5	4.47	23.69
6	10.36	34.05
7	7.80	41.85
8	9.22	51.07
9	5.87	56.94
10	9.57	66.51
11	4.24	70.75
12	3.59	74.34
13	3.18	77.52
14	3.17	80.69
15	5.55	86.24
16	6.57	92.81
17	6.55	99.36
18	6.82	106.18
19	8.00	114.18
20	8.07	122.25
21	4.02	126.27
22	5.27	131.54
23	5.46	137.00
24	11.84	148.84
25	5.97	154.81

APPENDIX – 5

Formulae for field density tests

- Weight/mass of sand in the cone = M4
- Mass of sand in the hole = M2 – (M3 + M4)
- Density of sand = Mg/cm^4
- Volume of the hole = $\frac{M2 - (M3 + M4)}{M}$
- Mass of soil from the hole = M1
- In situ wet density (MDD) = $\frac{\text{Mass of soil from the hole}}{\text{Volume of the hole}}$
- Moisture content = W (%)
- In situ dry density (DD) = $\frac{\text{In situ wet density}}{1 + w/100}$
- Maximum dry density (MDD) obtained from BS Heavy compaction test = D
- Optimum moisture (OMC) obtained from BS Heavy compaction = M%
- Relative compaction (%) = <u>In situ dry density</u> X 100
- Degree of compaction (%) = $\frac{DD}{MDD}$ X 100

APPENDIX – 6

Field observation questionnaire

A. Road base using lime or cement

1. Minimum thickness to compact one layer
2. Maximum thickness considered to compact one layer
3. Minimum – maximum thickness of road base

B. Sub base

1. Minimum thickness to compact one layer
2. Maximum thickness considered to compact one layer
3. Minimum – maximum thickness of road base

C. Subgrade

1. Thickness of material s used to repair improved sub grade layers
2. Minimum thickness of materials used to repair improved subgrade layers
3. Maximum thickness used when compacting
4. Design CBR values for naturally or modified gravel

D. Wearing courses

1. What are the road bear distresses?
2. What is the thickness and nature of wearing course?
3. What are the traffic levels?

E. Effects resulting from repaired utility cut distress on road structural pavements cost

1. 2007
2. 2008
3. 2009

F. Projects costs

1. 2008/9
2. 2009/10
3. 2010/11

G. Life span

1. When was the road constructed?
2. How long has it taken?
3. What was the design standard?

4. What is the current state of the road?

H. Unnecessary traffic jam

1. Where is the traffic jam in Kigali?
2. What is the cause?
3. What is the level of traffic jam?