UNIVERSITY OF ZIMBABWE

Faculty of Engineering and the Built Environment

Department of Construction and Civil Engineering

Level 5 Project

INVESTIGATING THE USE OF EARTHZYME SOLUTION AS A ROAD STABILISER IN PAVEMENT REHABILITATION: A CASE STUDY OF A 2KM SECTION OF CHITUNGWIZA ROAD.

By

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A project report submitted in partial fulfilment of the requirements of the Bachelor of Science Degree in Civil Engineering.

June 2023

DECLARATION

I**, Musekwa Millicent**, do hereby declare that this project report is a result of my original research work with the help of my supervisors, except where clearly and specifically acknowledged. This research is being submitted for the Bachelor of Science Honours Degree in Construction and Civil Engineering. This project has not been submitted in any form before for any degree or examination in any other university.

DEDICATION

This project is dedicated to my parents Mr T. and Mrs S. Musekwa, I would have never done this research if it was not for you. Behind every daughter who believes in herself is a parent who believed in her first. I am immensely grateful for your prayers, love and support.

ACKNOWLEDGEMENTS

I would like to thank God Almighty, the provider of good health during the execution of this project. I would like to express my profound gratitude to my supervisors, Ms. P. Mutekwa and Prof. L.D. Vassileva for their assistance through comments and guidelines during the research period. I would also like to give thanks to the Civil Engineering technical staff (namely Mr. Chinyama and Ms. Kunaka) and the Ministry of Transport Central Laboratory staff for helping me with my laboratory tests for this research project. I give sincere appreciation to Eng. M. Meki and Eng. B. Mapangire for shedding light to my project. Special mention goes to my family, friends and colleagues who assisted, motivated and were always positive throughout the research period.

ABSTRACT

Pavement rehabilitation aims to long-term improve the condition of the road. It is a process which involves comparing the components of the existing pavement to those needed for the new pavement. This is done to come up with a sustainable road design thus a pavement design which is cost-effective, environmentally friendly, safe and durable during its design life. Chitungwiza road is severely damaged with potholes, the road condition is very poor, shoulders are overgrown with vegetation which indicates poor surface drainage, and the design life has exceeded, therefore the road requires rehabilitation. This research project suggests the use of a sustainable liquid road stabiliser, called EarthZyme solution (EZ), in flexible pavement rehabilitation construction. EZ is a derivative of sugarcane which consists of surfactants, electrolytes and enzymes. It frees the clay fraction in a soil specimen from water enabling the specimen to be compacted into a denser form with low permeability.

In-situ and laboratory tests were conducted to determine material in-situ strength, density-water relationships, shear strength parameters, suitability of existing material to be stabilised with EZ and for parameters obtained to be used in design. In terms of effectiveness, the soaked CBR results for stabilised specimen showed a 77% increase in strength from the untreated soaked CBR results. As discussed herein, it is evident that treated specimen increased strength on day 28 as compared to day 7, based on the CBR test results, which means strength development gradually continues with time.

The study also presents a proposed design of a 2km flexible pavement which is 7/9m wide with 2 bases, granular for base1 and stabilised for base 2, and a double dressing seal for Chitungwiza road rehabilitation program. Ministry of Transport and SATCC standard manuals were used during design. Compared to the design which includes the conventional method of cement stabilisation, a 10% reduction in construction costs was noted for the design which includes Base 2 stabilisation with EarthZyme solution.

Ultimately, based on the results of this study, EarthZyme solution is deemed feasible for use as a sustainable road stabiliser in pavement construction. It is recommended that Ministry of Transport and Infrastructure Development considers its implementation.

Keywords: *stabilisation, EarthZyme solution, Chitungwiza road rehabilitation, flexible pavement.*

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LIST OF ACRONYMS

EZ	EarthZyme
CIR	Cold In-place Recycling
CBR	California Bearing Ratio
LL	Liquid Limit
MDD	Maximum Dry Density
DCP	Dynamic Cone Penetration
PI	Plasticity Index
PL	Plastic Limit
TP1	Trial Pit 1
TP2	Trial Pit 2
TRH 14	Technical Recommendations for Highways 14
ESA	Equivalent Standard Axle
SDG 9	Sustainable Development Goal 9
OMC	Optimum Moisture Content
BoQ	Bill of Quantities
TMH 9	Technical Methods for Highways 9
VCI	Visual Condition Index
MoTID	Ministry of Transport and Infrastructure Development
SATCC	Southern Africa Transport and Communications Commission
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials

CHAPTER 1

1.0 INTRODUCTION

Pavement rehabilitation design process involves a comparison between what exists and what is needed (Jordaan et al., 2015). A sustainable design is opted because its economical, environmentally friendly, socially beneficial and of adequate safety during its design life. This research project aims to investigate the use of a new liquid enzyme road stabiliser product called EarthZyme solution which is non-toxic, easy to apply and cost-effective. The suitability of road rehabilitation materials for stabilisation with EarthZyme solution is accessed and stabilisation is carried out only if the materials suit the requirements, for positive results. A 2km flexible road rehabilitation design is developed incorporating EarthZyme Base 2 stabilisation, based on existing, in-situ and laboratory results. Lastly, a cost comparative schedule is done to compare the flexible road rehabilitation design incorporating cement stabilisation against that of EarthZyme stabilisation.

This chapter comprises of background of the study, statement of the engineering problem, justification of the solution and research objectives that are to be followed during the course of the project.

1.1 Background

Pavement deterioration significantly impair the serviceability, safety and riding quality of roads (Zumrawi, 2016). Normally pavements start to deteriorate after their design service life has exceeded. In Sudan, potholes have become a security threat and assessments that were done reviewed that the roads require rehabilitation (Kampala Dispatch, 2021). Roads recently constructed were rapidly deteriorating after they were opened to traffic due to overloading since there was absence of weighbridges to monitor the traffic loads. As a result, this shortened the road's design life. Distresses observed on the pavement were ruts, cracks, potholes, depressions and damaged edges. The main cause of these failures was said to be excessive loading, changes in climatic conditions, poor drainage and poor maintenance.

Roadways are the most important infrastructure for the development of a country (Banister & Berechman, 2001). Roads are mainly used for a country's economic benefit through transportation. The road network construction enables job creation and encourages social and territorial cohesion whilst making sure that mobility and accessibility of goods and people throughout the country is effective. The Zimbabwean government has been striving to carry out Emergency Road Rehabilitation Programmes (ERRP) (Razemba, 2022). In Harare over 40 roads have been rehabilitated with the aim of improving their serviceability which is in line with the vision of attaining an upper middle-income society by the year 2030. Zimbabwe's road network is made up of flexible pavements. These roads have not been maintained for some time which means cost to improve state of roads is high. Flexible pavement construction relies on existence of natural gravels as a construction material. Availability of gravel pits close to the construction site has a huge impact on construction costs. This prompts stabilisation in order to improve available materials.

It is of utmost importance in transportation engineering to understand the geotechnical properties of road materials. Soil that resists mechanical change over time is deemed to be stable. Stabilisation is a technique used to enhance soil properties by combining it with other materials so as to make it stable (Firoozi et al., 2017). The use of a road stabiliser in pavement rehabilitation is to improve the bonding and strength of the layer material. Zimbabwe has mainly relied on cement and to a lesser extent lime and bitumen emulsion stabilisation. One major way of bringing about sustainability in road construction is the use of cost-effective stabiliser materials which produce durable pavements (Abdukareem et al., 2021).

EarthZyme (EZ) solution is a non-toxic road stabiliser material that is used with clayey soils to reduce the cost of road maintenance as it improves the compaction and increases the strength values. EZ is a liquid-based nano-material which uses the ionic exchange capacity principle to reduce the diffuse double layer that surrounds soil particles and decrease the soil's ability to absorb water. Ultimately, the EZ solution leads to a dispersed structure with smaller pore spacing thus reducing permeability (Abdukareem et al., 2021).

Most of Chitungwiza's roads are impassable due to wide and deep potholes (Chidhakwa, 2020b). Residents complain on the condition of the roads as it is damaging their vehicles. The local authority patches the potholes using gravel. This method of patching is not durable since the gravel is washed away during the rainy season and during vehicular movements leaving bigger and deeper potholes. The acting town clerk for Chitungwiza reported that only 3% of the roads are tarred and the major drawback being funding. The road network has aged and needs total rehabilitation. The potholes are becoming a hazard to motorists and their vehicles since they cannot navigate the roads.

1.2 Problem Statement

Some of Zimbabwean roads are severely damaged with potholes and this has caused the roads to be unnavigable. On some sections of Chitungwiza road, drivers have diverted from using traffic lanes to sidewalks and side drains. The shoulders of the road are overgrown with vegetation which indicates that there is poor surface drainage. The road has also exceeded its design life. There is a residential area on one side of Chitungwiza road and, an industrial and commercial area on the other. The day-to-day activities of the community as well as the productivity of industries is negatively affected by inaccessibility of this road due to the presence of potholes since there will be a delay on transportation time of the people and goods. Cement dust produced during construction causes, respiratory diseases such as asthma when inhaled; digestive tract irritations when swallowed; eye irritation and eventually eye damage when eyes are in contact with dust; as well as ulceration of skin and/or dermatitis when skin is in contact with dust, to construction workers. It also causes air pollution which affects the environment and communities around the site. Formation of potholes also leads to leaching of hydrocarbons present in wearing course material which in turn pollutes the environment (Ravi, 2020). During the rainy season, potholes collect water. The stagnant water breeds parasites such as mosquitoes which may cause malaria to the residents that are nearby. In addition, drivers' vision is impaired as they cannot see the water filled potholes which leads to damage of vehicle's tyres and passenger/driver discomfort.

1.3 Justification

Road rehabilitation aims to long-term improve the serviceability and riding quality of roads which is in line with Zimbabwe's vision of attaining an upper middle-income society by the year 2030 as stated in the National Development Strategy 1 (NDS1) macro-economic objectives. Emergency Road Rehabilitation Programmes (ERRP) are under way in the country, therefore reducing the cost of construction whilst producing durable pavements is a sustainable way to navigate these programs since modern construction requires cost-effective solutions. Portland cement is the most common road stabiliser material and its performance is remarkably good when the process is thoroughly monitored but the surface is susceptible to crack formation which in turn allows water which weakens the base. Cement also causes air pollution therefore, it is considered harmful to the environment and humans, and also requires more labour during construction (Beech, 2019). EarthZyme solution is a long-term soil stabiliser which uses available construction material with a plasticity index of at least 8 and a fineness index of more than 20%. This will reduce cost of construction by elimination of construction material haulage costs. It is also environmentally-friendly and non-toxic as compared to other conventional stabilisers such as cement and lime. The project will also lead to employment of local women and men. Sustainable development goal 9 (SDG 9, 'Industry, Innovation and Infrastructure') stresses on the need to build resilient infrastructure, promoting sustainable industrialisation and fostering innovation. Implementation of this project will produce a durable, quality and sustainable road infrastructure which will be one step forward towards achieving SDG 9.

1.4 Research Objectives

1.4.1 Main Objective

To design a cost-effective flexible pavement using EarthZyme solution as a sustainable road base stabiliser for road rehabilitation with cold in-place recycling in order to improve the road's operational efficiency.

1.4.2 Specific Objectives

a) To analyse the extent of pavement deterioration and traffic loading of the road.
b) To determine the soil properties of existing material through geotechnical investigations to check its suitability for stabilisation with EarthZyme solution.
c) To design a 2km flexible pavement for Chitungwiza road rehabilitation program.
d) To develop a construction cost comparative schedule for EarthZyme stabilisation against the conventional method of using cement stabilisation.

CHAPTER 2

2.0 LITERATURE REVIEW

Chapter 2 outlines theories, concepts, facts and figures that will help the researcher and the reader to have a greater understanding of pavement rehabilitation process and the use of EarthZyme solution as a road stabiliser. The chapter also includes a discussion on the methods to be used in the research project.

2.1 Pavement

A pavement is a durable hard surface that is constructed with the intention of carrying vehicular traffic or pedestrians (Bhushan, 2019). Its main purpose is to distribute imposed vehicle loads to the roadbed through different layers so that the loads will not exceed its bearing capacity. A properly constructed road must provide low noise pollution, proper riding quality, sufficient skid resistance and favourable light reflective properties. Two major types of pavements are rigid and flexible pavements (Wirtgen Group, 2012).

2.1.1 Rigid pavements

A rigid pavement is a high strength thick layer overlying a bound layer (Bhushan, 2019). Examples of rigid pavements are prestressed concrete pavement, continuous reinforced concrete pavement and jointed plain/reinforced concrete pavement.

2.1.2 Flexible pavement

A flexible pavement is a road constructed from naturally occurring materials with bound upper layers, lightly cemented or bituminous binders, to achieve higher strength requirements (Ministry of Transport and Energy, 1989a). Examples of flexible pavements are conventional pavement and full depth asphalt pavement (Bhushan, 2019).

2.2 Pavement layers

Flexible pavements are constructed in layers. Figure 2.1 shows a pictorial representation of flexible pavement layers followed by definition of the layers.

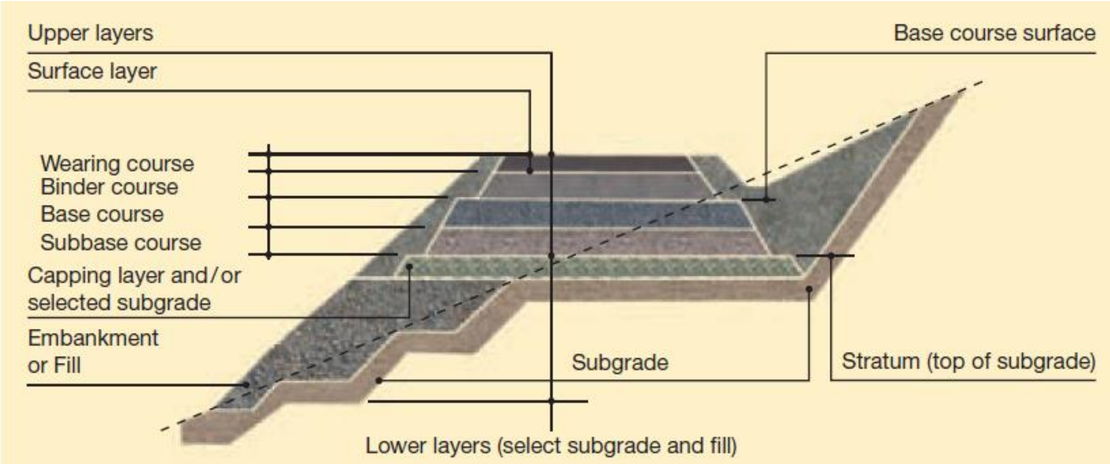


Figure 2.1: Flexible pavement layers (Wirtgen Group, 2012)

- **Wearing course**

  The wearing course is the surface of the road, it is the road's interface with traffic and the environment. Its function is to protect the pavement from both traffic and the environment, providing a strong and water-tight layer.
- **Base**

  The layer which provides the wearing course with structural support and protects the subgrade against deformation.
- **Sub-base**

  This layer aids to the pavement's structural capacity. It gives a strong platform where the base can be compacted adequately.
- **Subgrade**

  It is the foundation of the pavement and the in-situ soil on which the road is to be constructed. Sometimes called the roadbed.

Road design states that the strongest material is placed at the top of the pavement where imposed load stresses are highest and weakest at the bottom. Traffic wheel load is distributed from the wearing course to the roadbed.

2.3 Pavement deterioration

Flexible pavements are affected by many factors which result in different types of damages. Some of the major types of pavement failures are described in the following sections according to Michael et al. (2016).

2.3.1 Bleeding

Bleeding occurs when asphalt binder fills voids during hot weather or traffic compaction and expands onto the surface. This is caused by low air voids, excess prime or tack coat and/or excess asphalt. Figure 2.2 shows a road that has a bleeding distress.

Figure 2.2: Bleeding pavement (Pavement Interactive, 2020)

2.3.2 Depressions

Areas on pavement surfacing that have a slightly lower elevation than the surrounding areas. These areas become visible after a rainstorm due to stagnant water on the pavement. They are also known as birdbaths. Depressions are mainly caused by uneven thickness of succeeding layers, unequal compaction and settlement of the foundation. Depressions can be repaired by patching the lower areas.

2.3.3 Cracking

Types of cracks that form on a road are longitudinal, transverse and fatigue cracks. Longitudinal cracking occurs parallel to the centreline of the pavement. Transverse cracking occurs perpendicular cracks to the centreline of a pavement. Fatigue cracking is a series of interconnected cracks caused by fatigue failure of the surface under repeated traffic loading.

Environmental cracking occurs due to UV light from the sun, heat, and oxidation cause asphalt pavements to shrink forming cracks. Figure 2.3 shows cracking on the edges of the pavement.

Figure 2.3: Surface cracks (Pinard & Geddes, 2020)

2.3.4 Ravelling

This is failure where the upper layer of the asphalt disintegrates due to excessive water intrusion. This causes aggregate particles to separate and erode leaving a rough surface appearance. Ravelling occurs in excessively porous asphalt and when asphalt is placed at an unsuitable time. Sealing the affected area with sand, chip or micro-surfacing can repair solutions of this failure type.

2.3.5 Rutting

Ruts are channel-like depressions caused by wheel tracks as shown in Figure 2.4. As heavy traffic moves on the pavement, they start to compact the asphalt surface forming ruts. Ruts mainly form on pavements where there is lack of compaction, improper mix, insufficient layer thickness, moisture penetration and horizontal movement of layers under traffic load. Minor ruts are simply filled and provided with an overlay but in severe rutting scenarios, the damaged area is removed and replaced with a new layer.

Figure 2.4: Rutting pavement (Piotr, 2021)

2.3.6 Potholes

Potholes are small depressions on pavements' surface that can penetrate deep up to base course. They are formed from prolonged water ingress into the pavement through existing surface cracks. Flexible pavements are highly vulnerable when they get in contact with water. Water can be in the form of diesel spillages or rainwater. Pavements fail when there is water intrusion into the pavement, due to poor drainage, through cracks formed in the pavement. During winter or cold temperatures, the water will freeze thereby increasing in volume and decrease in material density. Any temperature drop will cause the frozen water to thaw and evaporate creating a void on the surface (Naveen et al., 2018). Water is therefore the prime cause of pothole formation. Figure 2.5 shows a pavement that has failed due to potholes.

Traffic load repetition could be a major contributing factor to pothole formation since as vehicles move, small surfacing particles are created and carried away. Mechanical damage by vehicle rims has the same effect. Poor maintenance culture also contributes to massive pothole damages. Repair of any crack formation on the pavement help in preventing the formation of potholes (Patel et al., 2008).

Figure 2.5: Pothole damage on road (Chidhakwa, 2020a)

Potholes not only damage vehicles but cause serious road accidents. During the rainy season, potholes collect water which act as breeding ground for mosquitoes and other parasites. As a result, if the mosquitoes are malaria causing, the surrounding residential area is affected.

In most cases potholes are pothole repair boundaries are defined and the old pavement in the pothole is trimmed to a regular geometrical shape and removed. The depression is then cleaned to make it free from any fines or water. Tack coat is applied on bottom and sides of the hole for bonding between existing pavement and patched material. It is then filled with patch material such as cold mix, gravel, soil crit, or premix open dense graded asphalt, depending on availability of material and compacted. Deeper potholes are treated in two or more layers but badly damaged roads are costly to repair in this manner therefore pavement rehabilitation is considered.

2.4 Pavement visual assessment

Pavement condition survey is done for the purpose of observing distress types and their severities. The evaluation of the pavement condition is done according to the road user and road engineer. The road user considers the pavement as a service therefore its condition is linked to its level of service. The road engineer considers the road as a structure which carries load. Pavement visual condition assessment is the first step in the procedure for road maintenance and/or road rehabilitation design (Pinard & Geddes, 2020).

2.4.1 Technical Methods for Highways 9 manual procedure

TMH 9 manual represents the Technical Methods for Highways 9 manual. It is a manual for flexible roads' visual assessments compiled under the auspices of the Roads Coordinating Body (RCB), Committee of Transport Officials (COTO), and Road Asset Management Systems (RAMS) Subcommittee. The basic categories for visual assessment for flexible roads are shown in Table 2.1.

Table 2.1: Categories for visual assessment of flexible pavements (Committee of Transport Officials et al., 2016)

Engineering Assessment	Functional Assessment
a. Surfacing ▪ Current surfacing type ▪ Macro Texture ▪ Voids ▪ Surfacing failures ▪ Surfacing cracks ▪ Aggregate loss ▪ Binder condition ▪ Bleeding/flushing b. Structural ▪ Cracks • Block • Longitudinal • Transverse • Crocodile ▪ Pumping ▪ Deformation ▪ Patching ▪ Failures/potholes	▪ Roughness ▪ Skid resistance ▪ Surface drainage ▪ Shoulders (unpaved) ▪ Edge effects • Edge breaking • Edge cracks • Drop-off

Brief description, according to the TMH 9(b), of the items in the Table 2.1 is given in the following section.

ENGINEERING ASSESSMENT

The engineering assessment for flexible pavements is split into 2 categories namely, surfacing and structural. The categories are described as follows.

SURFACING

Surfacing type

Surfacing type is named according to the material used. Technical Recommendations for Highways 14 (TRH 14) developed codes for different surfacing types as shown in the Table 2.2.

Table 2.2: TRH 14 codes for various types of surfacing (Committee of State Road Authorities, 1985)

Code	Material description
AC	Asphalt surfacing- continuously-graded
AG	Asphalt surfacing- gap-graded
AS	Asphalt surfacing- semi-gap-graded
AO	Asphalt surfacing- open-graded
S1	Surface treatment - single seal
S2	Surface treatment - multiple seal
S3	Sand seal
S4	Cape seal/ Single seal and slurry
S5	Slurry seal

Macro texture

Under wet conditions, macro texture plays a vital role in skid resistance. A course textured surface requires treatment with fine slurry to satisfy good skid resistance. Therefore, macro texture highly depends on aggregate size and amount of binder in a layer. It can be expressed as either fine, medium, medium-coarse or coarse, or varying.

Voids

The quantity of interconnected surface voids is directly influenced by aggregate size and the amount of binder content. The number of voids is determined by the ability of a diluted emulsion to be absorbed by the pavement.

Surfacing failures

Surface failure is mainly caused by aggregate and binder loss which leads to exposure of the underlying layer.

Surfacing cracks

This is cracking of the bituminous surfacing only. The cracks are normally caused by shrinkage of the surfacing as a result of reduced binder volume due to aging or loss of lighter oils. Rolling of asphalt during construction and edge breaking are also causes of surface cracks.

Aggregate loss

Aggregate loss can also be referred to as ravelling. Traffic abrasion mainly cause surface aggregate loss. The activity of aggregate loss must be assessed as either being active or non-active.

Binder condition

Bituminous binder become dry and brittle with time. The brittleness assessment of a pavement is mostly influenced by temperature. The colour of the binder indicates its brittleness. Shrinkage crack patterns indicates the binder’s dryness.

Bleeding/flushing

This defect occurs when excess binder moves upwards to the top of aggregates on the surface of the pavement.

STRUCTURAL

Structural engineering assessment involves evaluation of current pavement structure condition as shown by visible distresses. These defects will be a result of deterioration of the structure's strength caused by traffic, climate, ingress of water, poor quality material, age of pavement and poor surfacing. The following modes of failure indicates deterioration of the pavement structure.

Cracks

Structural cracks include block, longitudinal, transverse and crocodile cracks. Block cracks have a definite pattern and are commonly caused by the shrinkage of treated pavement layers (stabilised layer). Longitudinal cracks are line cracks running longitudinally along the pavement. They are mainly due to poor construction techniques such as asphalt overlay joints and active clay subgrades. Transverse cracks are line cracks which runs across the pavement. Traffic action on these cracks will eventually lead to severe distress.

Pumping

Pumping occurs when fine material is pumped to the surface due to high pore pressure under traffic load, normally through cracks.

Deformation

Deformation is the change in the profile of the road. Types of deformation include rutting and settlement. The degree and extent of rutting and settlement is used to rate structural deformation.

Patching

Structural patching indicates existence of previous defects. The average size of the structural patches gives an indication of the extent of the distress type that was repaired by the patch.

Failures/potholes

Potholes are secondary form of distress that develops from cracking or extreme aggregate loss. They progress from the top to the bottom of the road structure. Rating of this type of distress is done according to the pothole sizes.

FUNCTIONAL ASSESSMENT

This assessment depicts the serviceability of the road as perceived by the road user. The level of service is defined by comfort, safety and speed of travel.

Roughness

Roughness can also be interchanged by the term riding quality because it is rated by the quality of the ride as being smooth, bumpy, comfortable, unpleasant, or unsafe. This is mainly determined by the following

i. The evenness of the road profile – longitudinal deformation and rutting,
ii. Aggregate loss leading to formation of potholes and depressions, and
iii. Uneven patching.

Skid resistance

It is the ability of the road surface to prevent skidding when the surfacing is wet. Surface texture largely determines skid resistance. Problems relating to poor skid resistance are bleeding and polished aggregates hence it is rated with respect to these properties.

Surface drainage

Surface drainage is the ability of the road to keep the paved area free from water. This is also in relation to the extent of water ponding on the pavement during and after rain. Drainage affects skid resistance therefore it is an important issue in pavement construction. Rutting, alignment and overgrown shoulders are some examples of problems leading to inadequate surface drainage.

Shoulders (unpaved)

Unpaved shoulder is the area outside the surfaced pavement. It is rated as the availability of the shoulder as a safe area for stopping. The following are examples of reasons which makes the unpaved shoulder unsafe:

i. Erosion by water
ii. Erosion by traffic movement
iii. Level difference between carriageway and shoulder
iv. Width of the unpaved shoulder (narrow)
v. Cross-sectional area of the shoulder (too steep)
vi. Unpaved shoulder overgrown (vegetation)

Edge defects

This type of distress is most common on narrow roads where traffic moves closer to edges. Edge defects include edge breaks, edge cracks (both transverse and longitudinal) and drop-off.

Edge break

This is when the edges at the outside of the surfacing breaks away. It is usually due to poor maintenance of the unpaved shoulders. The degree of edge breaking is rated by the average distance from edge of pavement to the maximum points of breakage.

Edge cracks

Short transverse cracks start at the edge of the road and migrate inwards whereas longitudinal cracks occur within 300mm of the edge of the road.

Drop-off

Drop-off is a step between the surfacing and the unpaved shoulder. Drop-off is rated by the size of the step.

A table is provided in the TMH9 manual for the overall condition rating for the pavement under study. A less subjective condition rating is found by calculating Visual Condition Index (VCI) using degree, extent and weights of the road defects. For functional assessment items, an extent of 5 is assumed. Overall pavement condition from the table is not included in the VCI calculation. Table 2.3 shows the categories of the road condition according to the calculated VCI.

Table 2.3: Measure of road condition according to VCI (Pinard & Geddes, 2020)

Degree	VCI
Very good	85-100
Good	70-85
Moderate	50-70
Poor	30-50
Very poor	0-30

2.5 Road stabilisation

Soil stabilisation methods are widely used for road construction to improve the properties of the subgrade material. Use of new additives and stabilizers to improve soil properties can reduce the cost of construction and reduce the possible negative effects on the environment (Almeida et al., 2022). Modified stabilisation, especially chemical binders, are used to enhance surface wear characteristics, and slow down rate of deterioration which leads to pothole formation.

2.5.1 Mechanical stabilisation

Mechanical stabilisation is modification of the physical properties of the soil through compaction, soil blending or placing a barrier onto the soil (Maregesi, 2020). This stabilisation improves the soil's porosity and inter-particle friction. This mechanism is cost-effective because it promotes the use of locally available materials in a fit purpose approach.

2.5.2 Chemical stabilisation

Chemical stabilisation modifies the chemical properties of soil through the use of admixtures. Expected outcomes of different chemical stabilisers can be obtained from laboratory tests. There are different types of admixtures namely, Portland cement, quicklime, fly-ash, calcium chloride and bitumen. EarthZyme solution is a newly developed road stabiliser product. Chemical stabilisers work differently to stabilize soils, some act as binders while others increase soil density and alter moisture content.

2.6 EarthZyme solution as a road stabiliser

EarthZyme (EZ) solution is a liquid-based nano-material derived from sugarcane and manufactured by Cypher Environment as a cost-effective, environmentally friendly and long-term road stabiliser solution. It is made specifically for construction materials with a fraction of clay content (Almeida et al., 2022). EZ's main aim like any other stabiliser is to improve roads' geotechnical engineering properties by increasing CBR and density, as well as reducing permeability and swell.

EZ is a combination of enzymes, electrolytes and surfactants. These act on clay component of soil by releasing water to create a more compacted road through binding the materials permanently with clay (Cypher Environmental, 2022). This process increases the strength, wear resistance and endurance of the road.

2.6.1 Application of EZ

The surface of existing pavement is ripped and crushed, EZ is diluted and sprayed evenly over the material at optimum moisture content, and the layer is compacted and cured. Initially EZ stabilised base is cured for seven days but it continues for 28days. After application of EZ, the clay component will no longer attract water molecules therefore allowing water in contact with the road to drain freely.

2.6.2 Benefits of EZ

EZ is also a dust suppression material. Its treatment improves visibility on construction sites, as well as reduce occupational diseases and potential safety hazards such as lung problems and accidents respectively. EZ is environmentally friendly and non-toxic to roadside vegetation. The road is even stronger during wet weather. EZ application minimizes future rutting and erosion of base material. EZ stabilisation is simple and easy to apply, it also requires equipment used in conventional road construction. EZ uses in-situ materials over traditional materials like aggregates and gravel. The use of EZ stabiliser solution reduces long-term maintenance. EZ is less bulky since it is transported as a concentrated material and diluted on site.

2.6.3 Case study

Construction of a 7.2km road in Huiyang District, China.

As can be seen in Figure 2.6, a 7.2km road in Huiyang District was successfully constructed using EarthZyme solution as a road stabiliser (Cypher Environmental, 2022). The site for the road is hilly therefore the road had to be built with the assurance of long-term road base safety and support. Construction of EZ stabilised road lowered fuel consumption of vehicles by 17.4% due to the less deflection of the road. Significant dust reduction of up to more than 60% led to improved visibility of the site and reduced occupational diseases as well as potential safety hazards which were brought by high dust concentrations. The road proved that its strength and surface evenness were still satisfactory after one year. In this project, EarthZyme solution demonstrated its effectiveness beyond a shadow of doubt.

Figure 2.6: Construction of a 7.2km road constructed in Huiyang District using EZ stabiliser (Cypher Environmental, 2022).

2.7 Geotechnical investigations

Geotechnical investigations are carried out in order to determine the geotechnical characteristics of the sub-surface conditions at the site that can affect pavement designs. A geotechnical engineer is responsible for predicting the behavior of the ground under changes proposed for construction activities and to recommend the proper work to be done before construction begins. The results of these investigations influence the designs and other aspects involved in the project. New construction materials which suit the ground conditions maybe recommended in the process.

A desk study is first carried out and during this planning process information is collected. This information includes topography of the site, nearby existing roads, materials and methods used in the design and construction of the existing nearby roads. This is followed by a field reconnaissance which is the first site visit. This visit helps to determine other information not visualized and confirming the features found during the desk study. It also involves checking the actual ground conditions and the type of soils present. Soil samples are taken for laboratory testing of various soil parameters which can be used in the pavement design. A geotechnical report is then produced which helps in designing the pavement. The following is a brief explanation of the tests included in the geotechnical report.

2.7.1 In-situ DCP test

The DCP test is done in-situ to determine the ground bearing capacity of the road in order to analyse the strength variability of the road sub-surface as well as comparing strength capacity of sub-sections (Paige-Green & Plessis, 2009). This is done to guard against shear failure and unreasonable ground movements due to traffic loading. The apparatus is difficult to use on gravelly or very stoney areas.

2.7.2 Particle size distribution tests

Sieve analysis is a method used to determine the percentage by mass of coarse-grained soils. The soil sample is passed through a series of different standard sieve sizes arranged in descending order. Mass retained in each sieve is recorded and percentage passing calculated. The sieve analysis is presented as a curve on a semilogarithmic plot (Craig, 2004).

The fine-grained fraction of the coarse soil is determined by sedimentation method using a hydrometer. The hydrometer test measures the change of specific gravity of a soil-water mixture with time. The test is based on Stokes law which governs the settling velocity of spherical particles in suspension. A hydrometer is used to determine the grain size distribution of the particles falling out of suspension. Sodium hexametaphosphate is used as a dispersing agent. The specific gravity of the soil-water mixture decreases as the soil particles fall out of suspension. Strict temperature control is observed during the test. Figure 2.7 shows the movement of the hydrometer bulb with time as the particles settle.

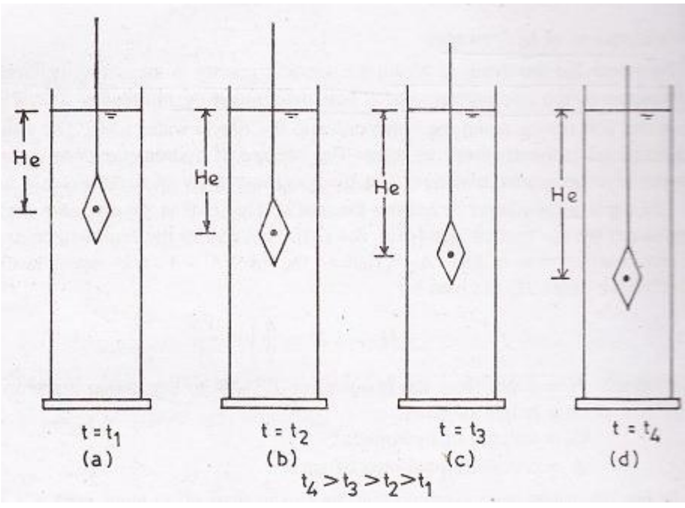


Figure 2.7: Hydrometer's downward movement with time (Gopal, 2011)

2.7.3 Atterberg limits tests

The Atterberg limits also known as consistency limits consists of plastic limit, liquid limit and shrinkage limit of the soil. The values of the liquid and plastic limit are used to classify the fine-grained solid and to understand the soil behavior under various moisture contents. The two values are also used in the calculation of plasticity index. The plasticity index is used to predict the plasticity, cohesiveness, permeability, shear strength and compressibility of the soil. ***Liquid limit*** is the minimum water content expressed as a percentage at which the soil changes its state from liquid to plastic state. ***Plastic limit*** is the water content at which a soil sample changes state from semi-solid to plastic state as it is rolled into a 3mm diameter thread. Plasticity index is the range of water content between liquid limit and plastic limit. According to (Craig, 2004) plasticity index is calculated using Equation 1:

$$Plasticity\ index, PI = Liquid\ Limit\ (LL) - Plasticity\ Limit\ (PL) \qquad \textit{(Equation 1)}$$

2.7.4 Standard compaction test

Compaction is a procedure where soil particles are packed close together increasing its density whilst reducing air volume within the specimen (Craig, 2004). The soil particles are packed in a cylindrical mould by kneading using a rammer. Dry density is the measure of degree of compaction which is calculated using Equation 2:

$$Dry\ density, \rho_d = \frac{\rho}{1+w} \qquad \textit{(Equation 2)}$$

where, $\rho\ is\ bulk\ density$

w is water content

Compactive effort is the mechanical energy supplied during compaction. Low Compactive Effort (LCE) is achieved by compacting 3 layers of soil sample in a cylindrical mould of volume 2250m^3 until full, each layer compacted by 60 blows of a standard hammer of 2.5kg mass and 300mm length of drop for each blow whilst High Compactive Effort (HCE) is achieved by compacting 3 layers of soil sample in a cylindrical mould of volume 2250m^3 until full, each layer compacted by 56 blows of a standard hammer of 5kg mass and 450mm length of drop for each blow. The described methods are under Method B specification where maximum particle size is less than 37.5mm (Ministry of Transport and Energy, 1989d). A standard compaction test involves varying water content by adding different volumes of water in each specimen, a curve of dry density against water content is plotted and optimum moisture content at maximum dry density is obtained from the graph. Ultimately, compaction results in less permeability, less compressibility and increased strength.

2.7.5 California Bearing Ratio test

The California bearing ratio method is used to determine the strength of soils. This is determined by allowing a standard solid cylindrical plunger to penetrate the soil specimen at a specific rate and measuring the relationship between load and penetration (Ministry of Transport and Energy, 1989d). CBR is defined as the ratio of the load and the standard load. A curve of load against penetration is plotted and adjusted if it is a concave. CBR values are quoted at 2.5mm and 5.0mm penetration, whichever is greater.

2.8 Road rehabilitation design

Road evaluation and rehabilitation is a fundamental part of managing a pavement system (Jameson, 2021). To come up with a road rehabilitation design, existing road design, soil surveys and axial loading are determined first. Sometimes, roads require treatment to strengthen them in order to accommodate future traffic. A pavement that requires road rehabilitation typically varies in both longitudinal and transverse direction in terms of structural capacity. It is therefore cost-effective to divide existing pavement into sub-sections of relatively uniform strength. The DCP test as well as the extent of pavement failure is then used to determine homogeneous sub-sections.

The purpose of pavement design is to produce a structural pavement that will carry traffic conveniently and safely at minimum cost. This involves selection of construction materials as well as layer thicknesses. The main factor that affects design performance of pavement is the number of repetitions of individual axle load.

2.8.1 Cold-in-place recycling

Cold in-place recycling (CIR) refers to milling of the existing pavement up to a depth of 125mm, crushing the recycled asphalt pavement to a maximum size of 37.5mm, mixing with suitable material enhancers and laying the material back down on the road using a grader.

Mix design optimizes the addition rate and the composition of the added material enhancer (recycling additive). Other materials can also be added to blend the material to make it suitable for construction of a durable pavement.

2.8.2 Traffic counts

Traffic counts are counts of vehicular traffic conducted along a particular road at a particular point and period. Traffic counts are done either manually by visually observing and recording traffic, or automatically by use of an installed temporary or permanent electronic traffic recording device, such as a pneumatic counter. Table 2.4 shows categories of vehicles according to their wheel/axle loads.

Table 2.4: Classification of traffic (Ministry of Transport and Energy, 1989c)

Type of vehicle		**Category**
1	Light passenger vehicle	Station wagon, kombi, cars, cars towing caravan
2	Commercial vehicle (Light goods vehicles)	Net mass of less than 2300kg, with a red reflective strip at the rear of the vehicle
3	Omnibuses	Net mass of more than 2 300kg
4	Heavy goods vehicle	Net mass of more than 2 300kg, contains a chevron sign at the rear of the vehicle.
5	Abnormal load vehicles	Vehicles written abnormal at the front.

Except for light passenger vehicle and commercial vehicle, the other 3 types of vehicles are classified according to number axles.

2.8.3 Equivalent Standard Axle

The purpose of counting traffic is to estimate axle loads that vehicles impose on a road. These axle loads are crucial because they help in the prediction of the road damage caused by wheel loads over the design life. The process of estimating ESAs is illustrated in Figure 2.8.

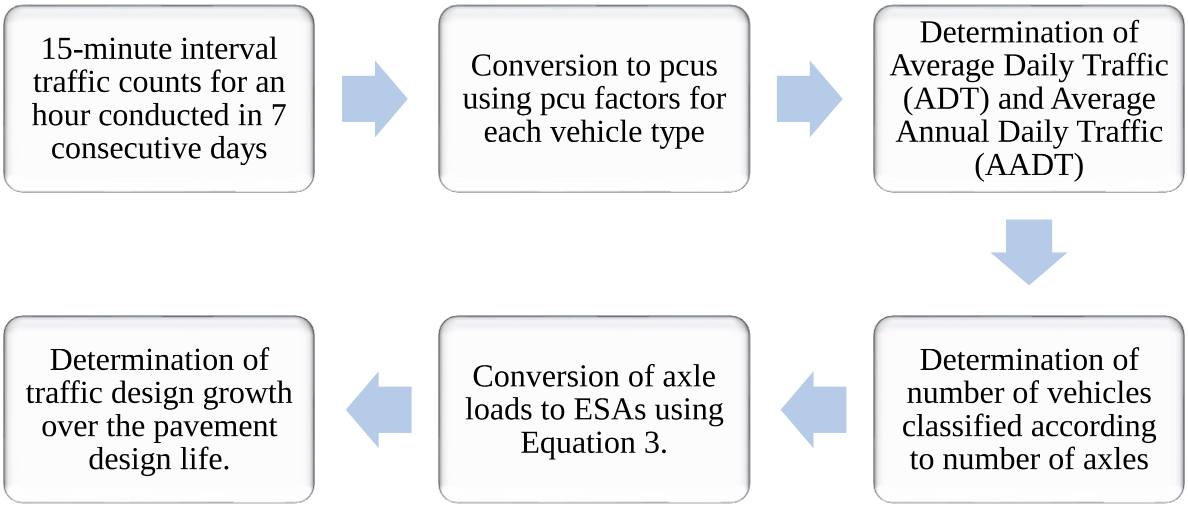


Figure 2.8: Process of estimating ESA for a road (Transport Research Laboratory, 1993).

According to (Ministry of Transport and Energy, 1989a), the axle equivalency factor is given by Equation 3.

$$EF = \left[\frac{L}{8.2}\right]^{n} \qquad \textit{(Equation 3)}$$

Where L is axle load in tonnes

n = 4 or 4.5 (for Zimbabwe n=4.5)

According to (Transport Research Laboratory, 1993) , the design traffic growth is calculated using Equation 4.

$$Cumulative\ Design\ Traffic, DT = ADT \times 365 \times \frac{[(1+r)^{n}-1]}{r} \qquad \textit{(Equation 4)}$$

Where ADT =Average Daily Traffic in veh/day

r = growth rate as a decimal.

n = design life in years.

2.8.4 Design traffic class

Description of traffic classes is shown in Table 2.5 and, according to TRH16.

Table 2.5: Traffic class descriptions (Committee of State Road Authorities, 1991).

Traffic class	Cumulative equivalent traffic (Million E80/lane)	Description
E_R	0.05	Residential access roads, Very lightly traffic Heavy vehicles: very few
E_0	0.2	Very lightly trafficked roads Heavy vehicles: very few
E_1	0.2-0.8	Lightly trafficked roads, mainly cars Agricultural vehicles Heavy vehicles: very few
E_2	0.8-3	Medium volume of traffic Few heavy vehicles
E_3	3-12	High volume traffic Many heavy vehicles
E_4	12-50	Very high volume of vehicles Many heavy vehicles
E_5	50-200	Exceptionally heavily trafficked roads

Ranges of design traffic is classified in Table 2.6 according to SATCC standard manual.

Table 2.6: Traffic class designation (SATCC, 1998)

Traffic class	T1	T2	T3	T4	T5	T6	T7	T8
Traffic ranges (Million ESAs)	<0.3	0.3-0.7	0.7-1.5	1.5-3	3-6	6-10	10-17	17-30

2.8.5 Subgrade strength

Table 2.7: Subgrade classes and description

Class	Design CBR	Notes
SG30	30	May be used as fill and sub-base layer material. Upper 150mm layer or the sub-base layer is usually compacted to 95% AASHTO density.
SG15	15-29	May be used as fill material and as selected fill layer. Upper 150mm layer or the selected fill layer is usually compacted to 95% mod AASHTO density.
SG 9	9-14	May be used as fill material. Upper 150mm layer usually compacted to 93% mod AASHTO density.
SG5	5-8	May be used in all fills. Upper 150mm layer is usually compacted to 93% mod AASHTO density.
SG3	3-4	May be used as fill material not exceeding 3m in height. Normally compacted to 93% mod AASHTO density.
SGE (Expansive soils)	<3	A soil is potentially expansive if it exhibits any two of the following properties: a) Liquid limit (LL) of the whole sample exceeds 55%. b) Clay fraction exceeds 20%. c) Free swell exceeds 60%

2.9 Project costing

Project costing in road construction is a process that involves evaluation of project in terms of monetary value. This is done by estimating volumes of different materials required and multiplying them with respective rates. A cost comparative schedule is carried out to determine the cost-effective solution for a project, otherwise the cost is justified with valid reasons. In most cases the costs are compared against the costs of traditional methods.

CHAPTER 3

3.0 MATERIALS AND METHODS

This chapter outlines the description of the study area, the research framework and the different methods of data collection and analysis used by the researcher in determining the suitability of using EarthZyme solution as a road stabiliser as well as incorporating it, EarthZyme solution, in pavement design for rehabilitation.

3.1 Study area

The study area is Chitungwiza road, which is a ring road round Chitungwiza urban centre which connects Mbudzi interchange to Seke road. The road follows a South-East direction from Mbudzi "interchange". Chitungwiza road was selected because there are sections of the road which are severely damaged with potholes and are unnavigable. The road is of importance because it connects the urban centre, Chitungwiza to Harare. This project focuses on a 2km section of Chitungwiza road from coordinates 17˚ 59' 59" S and 31˚ 01" 52' E to Puma service station with coordinates 18˚ 00' 47" S and 31˚ 02' 35" E. The locality map is shown in the Figure 3.1.

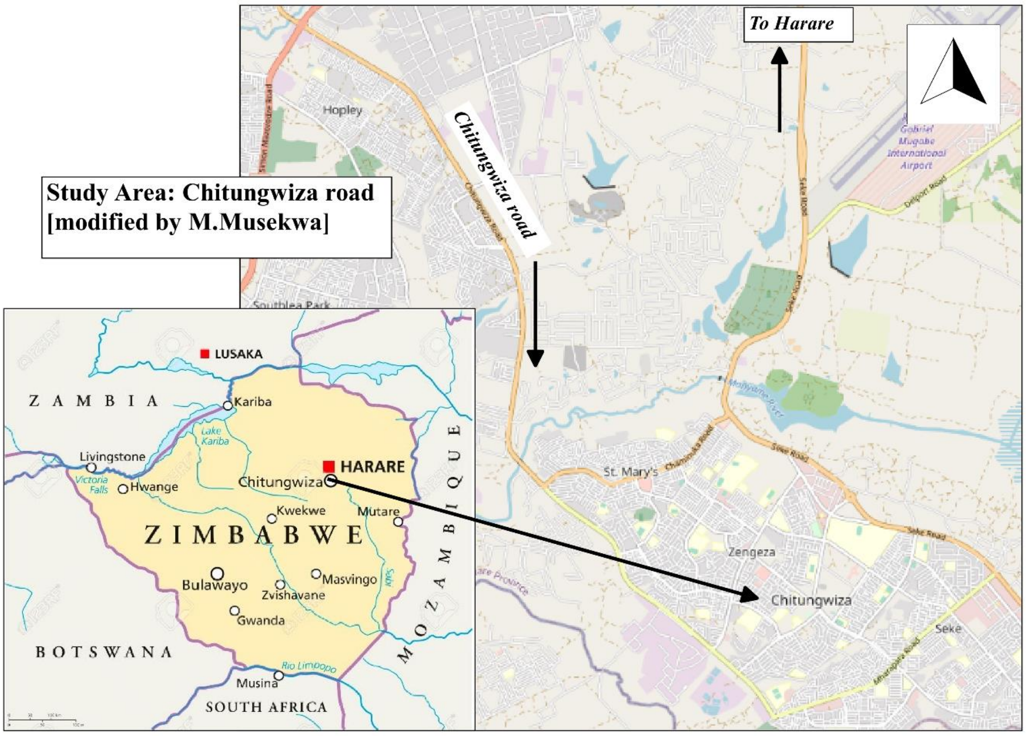


Figure 3.1: Locality map showing Chitungwiza road.

3.2 Research framework

Figure 3.2 shows the flowchart of the research framework followed in executing the project.

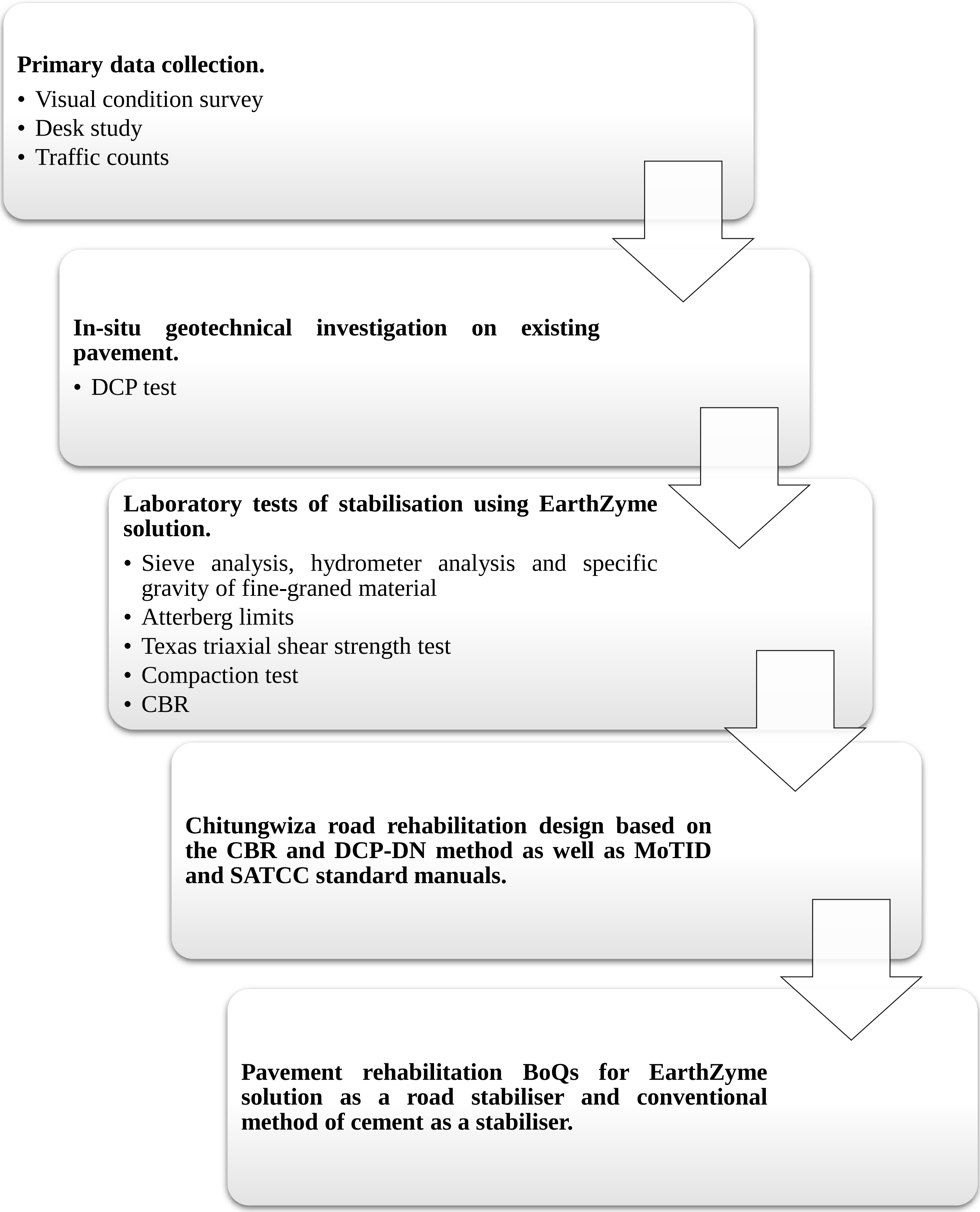


Figure 3.2: Flowchart showing the project research design

3.3 Methods of data collection and analysis

A non-inclusive and inclusive investigation, in terms of pavement structure, was done. The non-inclusive tests are non-destructive and the inclusive tests are destructive since trial pits were dug for investigation. The non-inclusive investigation done included the desk study, visual condition survey and traffic counts, as explained in detail in the following sections. The inclusive tests, DCP tests, were done as an in-depth investigation of the pavement structure to ascertain the strength of the existing road. Trial pits were also done as confirmatory tests to the inclusive tests and for sample collection which will be used to test EarthZyme solution as a stabilising agent in the laboratory. The following are the methods of data collection and analysis according to specific objectives.

<u>To analyse the extent of pavement deterioration and traffic loading of the road.</u>

3.3.1 Primary data collection

Visited the Municipality of Chitungwiza, interviewed the head of section at the Department of Roads to acquire information on Chitungwiza pavement design as well as available as-built drawings information and other relevant information on existing pavement such as traffic counts and road elevation data.

3.3.2 Visual condition survey

The condition of Chitungwiza road was determined according to Technical Methods for Highways 9 (TMH 9), Part B visual assessment procedure considering various distress types in order to analyse the extent of pavement failures as seen by the human eye. The 2km section under study was assessed to determine the overall state of the road. Engineering and functional assessments were done, degree and extent were allocated to each distress type and results were recorded on a visual assessment form shown in Appendix 1. A Visual Condition Index, VCI, was calculated to determine the category and description of the road condition.

3.3.3 Traffic counts

Traffic counts were conducted for 7 consecutive days during peak hours that is 0700-0800 or 1630-1730 to determine the number and composition of vehicles. The traffic was observed manually at a counting station point on the 2km section under study for one hour and recorded in 15minute intervals using the tally system as shown in Appendix 3. Traffic was categorised according to Ministry of Transport Traffic Manual (Ministry of Transport and Energy, 1989a).

To determine the soil properties of existing material through geotechnical investigations to check its suitability for stabilisation with EarthZyme solution.

3.3.4 Geotechnical study

In-situ geotechnical investigations were done on existing pavement as an in-depth analysis for the extent of pavement failure. Two trial pits were excavated to a depth of 1m using a pick and a shovel. Approximately forty-kilogram soil samples were collected at 0.5m and 1m depths using a shovel into respective labelled sacks. Description of existing pavement profile and in-situ DCP test were done during the digging of the trial pits. Layer thicknesses were measured and samples were also collected to conduct laboratory tests. Samples were oven dried before testing in the laboratory, other samples were kept in closed sacks such that they ascertained the in-situ moisture content.

In-situ test

The following test was conducted in-situ.

3.3.4.1 Dynamic Cone Penetration test

Dynamic cone penetration (DCP) test was done on the existing pavement to determine the pavement bearing pressure for the undisturbed state of the road layers. A 20mm diameter cone was driven into the ground by dropping an 8kg weight and the penetration after each blow as well as the DCP scale reading were recorded. Three people were present during the experiment where the first person held the instrument in a vertical position, the latter raised the hammer and the third person recorded results. Research Community Access Partnership (ReCAP) Low Volume Road (LVR) DCP v1.00 Software was used to analyse the DCP results. The author assumed the number of layers for the existing pavement according to the trial pits soil profile. DCP readings and number of blows were entered in the software. The software uses the DCP-DN method to produce layer strength diagrams for the test indicating inadequate layers for the pavement.

Laboratory tests

The following laboratory tests were conducted to determine and evaluate the effect of using EarthZyme solution as a road base stabiliser.

3.3.4.2 Sieve analysis

The test was carried out in accordance to BS1377 (Part 2: 1990: 9.1-9.3). Sieve analysis was done to determine particle size distribution for the suitability evaluation of the material to be stabilised by EarthZyme solution (BS 1377, 1990a). Wet and dry sieving was conducted in the laboratory. A 500g sample was weighed using an electronic balance. The sample was washed through a 0.75mm sieve under running water ensuring that the sieve is not overloaded. The washed sample was then placed in the oven to dry at a temperature of 105˚C - 110˚C for 24 hours. After 24 hours the sample was weighed and the mass was recorded. The dry sample was placed into the series of British standard series of sieves which were arranged in descending order. The stack was shaken vertically to allow the particles of different diameter to pass and/or retain into their respective sieve. Mass retained on each sieve was measured making sure there are no particles stuck on the sieve and results were recorded.

3.3.4.3 Hydrometer analysis

Hydrometer test was done according to ASTM D7928-17. The aim of the test was to determine soil compatibility with EarthZyme solution by finding particle size distribution of fine-grained soils passing through 75µm sieve by sedimentation process using a hydrometer. 40mg of Sodium hexametaphosphate was dissolved in distilled water to give a litre solution which was stored in a bottle with a stopper. 50g of the soil sample which passed through the 75µm sieve was placed in a conical flask and 125ml of the dispersing agent solution was added. The solution was stirred thoroughly and allowed to stand for 24hours. The sample was then transferred without any wastage of particles to a standard hydrometer analysis cylinder. The cylinder was filled with distilled water to the 1000ml mark. A rubber stopper was placed on top of the cylinder and it was tipped, turned upside down, 30 times in one minute. The cylinder was placed on the test site and a clock was started to record the elapsed time. Hydrometer readings were recorded at 1, 2, 4, 8, 15, 30, 90, 180, 240, 480 and 1440 minutes. Figure 3.3 shows setup of the hydrometer analysis test conducted in the laboratory.

Figure 3.3: Set up of apparatus used for hydrometer analysis test.

For specific gravity determination, density bottles were dried, weighed and their masses recorded. Soil sample of mass between 10-15g was placed in each density bottle and water to just cover the soil was added. The density bottles were placed in a desiccator without stoppers to remove air bubbles until there was no change on the gauge reading. Distilled water was then added to the mark on the neck of the density bottle and the bottle was weighed. The bottle was cleared and cleaned, distilled water only was added to the neck and the bottle was weighed. Specific gravity of fine-grained material was determined from the masses obtained and used during hydrometer analysis. Figure 3.4 shows the apparatus used in specific gravity determination in the laboratory.

Figure 3.4: Apparatus used for specific gravity determination.

3.3.4.4 Atterberg limits test

Atterberg limits tests were done according to BS1377 (Part 2: 1990). These tests determine the suitability of material to be stabilised. The Atterberg limits tests namely, plastic limit and liquid limit were done in the laboratory.

Liquid limit

The Casagrande apparatus method was used to determine the liquid limit of the sample which passed through the 425µm BS sieve. 300g of the sieved sample was placed on a glass plate adding water as necessary and thoroughly mixed with distilled water using palette knives until a smooth homogeneous paste was formed. A portion of the mixed soil sample was placed in the Casagrande cup without entrapping air. The paste was then levelled parallel to the base and divided by driving the grooving tool along the diameter through the centre of the hinge keeping the tool normal to the surface of the cup. A sharp clear groove was formed and the crank of the Casagrande was turned at a rate of 2 revolutions per second so that the cup is lifted and dropped. This procedure was repeated until the two-sample come into contact at the bottom of the groove. The number of blows were recorded and the sample was taken for moisture content determination.

Plastic limit

A 20g sample that had passed the 425µm sieve was placed on a glass plate and mixed with water until it could be easily shaped into a ball. The sample was divided in two portions and rolled between fingers and a clean glass plate with sufficient pressure to form a thread of 3mm diameter and 150mm length as shown in Figure 3.5. The threads were broken into 6 pieces, placed in containers, weighed and placed in the oven for moisture content determination.

Figure 3.5: Plastic limit test.

3.3.4.5 Texas triaxial shear strength test

Triaxial shear strength test was done according to BS 1377: Part 8 (1990) manual. The consolidated undrained test was done in this project. Triaxial specimens were prepared using the trial-and-error method, at first, to determine the amount of soil required per mould which produces a compacted specimen with a height that is twice the diameter of the mould. The dial gauge used to measure the specimen height is shown in Figure 3.6.

Figure 3.6: Dial gauge used to measure the height of specimen.

After ascertaining the amount of soil required per mould, 5 samples were compacted to determine the Optimum Moisture Content (OMC). Using the determined OMC, another set of

5 samples was compacted and demoulded as shown in Figure 3.7. Porous stones were placed on the top and bottom faces of each specimen.

Figure 3.7: Samples prepared for triaxial shear test.

These specimens were consolidated under all round pressure before failure which was achieved by covering the samples with, first, a permeable membrane and, second, a rubber membrane. The samples were then soaked in water for 10 days. Figure 3.8 represents how the samples covered with membranes and saturated in a water bath. Saturation is done to ensure that pore water within the sample does not contain air (BS 1377, 1990b).

Figure 3.8: Saturation stage where samples were left to soak in a water bath.

After the saturation stage, the compression stage followed. Figure 3.9 represents how the samples were compressed and the axial stress was recorded at failure that is when the deformation dial gauge stopped. 2 specimens were exposed to zero confining pressure and the remaining 3 samples to different confining pressure.

Figure 3.9: Triaxial test compression stage

Using the results, Mohr-Coulomb plot is drawn for the failure conditions and shear strength parameters, cohesion and angle of shearing resistance, are ascertained.

3.3.4.6 Compaction test

Compaction test was done in accordance to TMH 1: Method A7 procedure (Eksteen, 1986). The test was done to determine the optimum moisture content and maximum dry density required for the soil sample. The oven-dried soil sample was divided into four portions each 7kg mass. Material particles greater than 19.0mm sieve were crushed by a steel tamper to crush them into smaller particles. Moisture content was varied by adding different amounts of water to the soil sample. Soil-water mixture was placed into pre-weighed moulds and 60 blows per each layer were applied using a hammer. The soil was compacted in 3 layers. The moulds were placed in water to cure and were taken for CBR determination.

3.3.4.7 California Bearing Ratio test

California Bearing Ratio test was done according to TMH 1 (1986): Method A8 procedure. The test was done to determine the bearing capacity of the stabilised disturbed soil sample and compare the results with the untreated soil to find the effect of adding EZ as a road stabiliser. The of curing, the moulds were placed on the CBR machine for testing. As the plunger penetrated the compacted soil, dial readings were noted and recorded. A representative sample was taken from the top and taken for moisture content determination.

3.3.5 Strength development using EarthZyme solution

The Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) obtained from the compaction test were used to determine the amount of water and soil needed per mould. A 2% reduction factor in moisture content was incorporated in the calculation of water to be added for moulds compacted with EZ solution.

Samples at 0.5m depth from TP1 and TP2 were compacted. Control samples were compacted with water only and treated samples were compacted with water mixed with EarthZyme solution as shown in Figure 3.10. Treated samples with EarthZyme solution used the ratio of 1litre of EarthZyme solution as to 33m^3 of compacted soil (Cypher Environment, 2009). The samples were cured for 7 and 28 days. Comparative, dry and soaked, CBR tests were done to determine the strength development of the stabilised sample with time. For soaked CBR test, the moulds were soaked for 96 hours (4days) prior testing.

Figure 3.10: Measurement of 1ml of EarthZyme road stabiliser and its addition to water in the soil sample during compaction.

<u>To design a 2km flexible pavement for Chitungwiza road rehabilitation program.</u>

3.3.6 Pavement rehabilitation design

Using the results obtained, a cost-effective road rehabilitation design was prepared. The design was based on CBR and DCP-DN methods. The design process was guided by SATCC and

Ministry of Transport standards. The pavement structure was chosen according to design traffic for the road as shown in Figure 3.11.

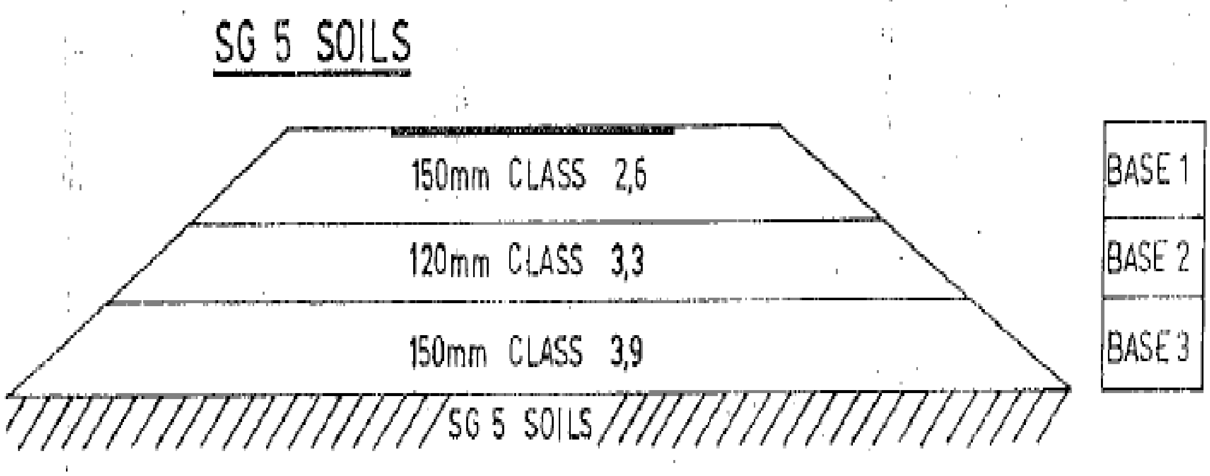


Figure 3.11: Pavement structure for design traffic of 0.3-1 million E80 (Ministry of Transport and Energy, 1989b).

The proposed road cross-section and long-section were drawn using AutoCAD (2022) and AutoCAD Civil 3D (2016) software, respectively. Existing survey points data was imported in AutoCAD Civil 3D to come up with the long-section drawing for the 2km section under study.

<u>To develop a construction cost comparative schedule for EarthZyme stabilisation against the conventional method of using cement stabilisation.</u>

3.3.7 Cost comparative schedule

Prepared Bill of Quantities to determine the impact of using EarthZyme road stabiliser vs cement stabiliser on construction costs using guidelines from the SATCC (1998) manual.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

This chapter presents results obtained in the form of tables, graphs and figures, as well as the discussion of the results where interpretation and explanation of the results is done. The scope of the investigations included walkover and traffic surveys as non-destructive tests to determine visual condition of road and traffic loading, in-situ DCP test to determine the strength of the in-situ material, geotechnical investigations on existing material to classify it and determine its suitability to be stabilised by EarthZyme solution, compaction and CBR tests of untreated and treated soil samples to determine the effectiveness of EarthZyme solution as a road stabiliser.

4.1 Visual condition survey

Figure 4.1 shows the visual condition of Chitungwiza road. Traffic is moving on the sidewalk of the road because the traffic lanes are unnavigable due to the presence of extensive potholes. Other pictures showing the condition of the road are presented in Appendix 2.

Figure 4.1: Chitungwiza road severely damaged with potholes, lorry navigating on sidewalk (Source: Author)

The following sections consist of descriptions and illustrations, using tables, of the degree, extent and comment of the condition of the pavement.

4.1.1 Engineering assessment

4.1.1.1 Surfacing

Current surfacing type is *surface treatment-single seal (S1).* The surfacing appear smooth, coarse aggregates are visible but the surface is not coarse because there is presence of fine aggregates in between the coarse aggregates, therefore the macro texture type is *medium*. The surfacing on some sections of the road is dense and no voids are visible whereas on other sections the voids are visible therefore the void class for the road is described as *none-few*.

Table 4.1 shows the degree, extent and comment on the surfacing engineering assessment that was done on Chitungwiza road based on the visual judgement of the author following guidelines in Technical Methods for Highways 9-Part B (Committee of Transport Officials et al., 2016).

Table 4.1: Pavement's surfacing engineering assessment

Features	**Degree**	**Extent**	**Comment**
Surfacing failures	5	5	Potholes were noted over large areas, having diameter greater than 300mm.
Surfacing patching	5	4	Some sections were patched over a large area using gravel.
Surfacing cracks	0	-	No cracks were observed.
Binder condition	5	5	Binder appeared dull and brittle.
Aggregate loss	5	4	Active aggregate loss in large areas.
Bleeding/flushing	0	-	No bleeding was observed.
Surfacing deformation/shoving	0	-	No shoving was observed.

4.1.1.2 Structural

Table 4.2 shows the degree, extent and comment that was done as the structural engineering assessment of Chitungwiza road.

Table 4.2: Pavement's structural engineering assessment

Features	Degree	Extent	Comment
Cracks	0	-	No type of cracks was seen.
Pumping	0	-	The pavement showed no signs of pumping.
Rutting	0	-	No visible rutting was observed
Undulations/settlement	0	-	No visible settlement was observed
Patching	4	5	The road was patched using gravel but it is not visible anymore because the gravel has been washed away by the rains.
Failures/potholes	5	5	Severe loss of surfacing material as well as severe depressions were observed.

4.1.2 Functional assessment

Table 4.3 shows the degree and comment that was done as the functional assessment of Chitungwiza road.

Table 4.3: Pavement's functional assessment

Features	Degree	Comment
Roughness	5	Ride very poor and very uncomfortable due to extensive potholes. Road deemed not safe.
Skid resistance	-	Skid resistance inadequate due to existence of potholes.
Surface drainage	3	Shoulder overgrown.
Shoulders (unpaved)	5	Shoulders are unsafe to be used as stopping area because there are some overgrown sections and others eroded.
Edge defects	5	Some sections of the road, the edge break was greater than 300mm which is considered a safety hazard to traffic. Edge cracks, longitudinal and transverse, were observed.
	1 & 3	On other sections the drop-off varies from approximately, less than 50mm and equal to 75mm.

The overall pavement condition was rated to degree 5 because the whole 2km section had severe potholes (Committee of Transport Officials et al., 2016).

Visual Condition Index is a value which encompasses the degree, extent and weighting of the pavement assessments. Calculation of Visual Condition Index (VCI) is presented in Table 4.4 and Equation 5. The condition of the road is then determined by Table 2.3 using the VCI value obtained.

Table 4.4: Calculation of VCI

Item		Degree	Extent	Weighting	F	F_{max}
Surfacing	Surfacing Failures	5	5	0.7	17.5	17.5
	Surface Patching	5	4	0.7	14	17.5
	Surfacing Cracks	0	0	0.7	0	17.5
	Aggregate loss	5	5	0.7	17.5	17.5
	Binder condition	5	5	0.7	14	17.5
	Bleeding and flushing	0	0	0.7	0	17.5
Structural	Cracks	0	0	1.2	0	30
	Pumping	0	0	1.2	0	30
	Rutting	0	0	1.2	0	30
	Undulations/Settlements	0	0	1.2	0	30
	Shoving	0	0	1.2	0	30
	Patching	4	5	1.2	24	30
	Potholes	5	5	1.2	30	30
Functional	Roughness	5	5	2.0	50	50
	Skid Resistance	0	0	1.0	0	25
	Surface Drainage	4	5	1.2	24	30
	Shoulders (Unpaved)	5	5	1.2	30	30
	Edge defects	5	5	0.7	17.5	17.5
Total					238.5	467.5

$$Visual\ condition\ index, VCI = 100(1 - C\sum F) \quad \textit{(Equation 5)}$$

$$C = \frac{1}{\sum F_{max}}$$

$$C = \frac{1}{467.5} = 0.002139$$

Therefore, $$VCI = 100(1 - [0.002139(238.5)]$$

= 49% (Poor - *from Table 2.3.)*

Therefore, it was concluded that the ***road requires rehabilitation*** due to extensive potholes.

4.2 Traffic counts

The data shown in Table 4.5 shows the actual number of vehicles recorded during peak hours at 15minute intervals. The total number of vehicles per hour per day for each category was determined and the average vehicles per hour was recorded.

Table 4.5: Traffic counts results

Day	Time	Light passenger vehicle	Commercial vehicle	Omnibuses	Heavy goods vehicle	Abnormal load vehicles	Total
Day 1: Sun	0700-0800	83	68	4	5	0	
Day 2: Mon	1630-1730	75	83	26	26	0	
Day 3: Tues	0700-0800	98	126	5	23	0	
Day 4: Wed	0700-0800	76	125	37	26	0	
Day 5: Thurs	1630-1730	192	153	14	20	0	
Day 6: Fri	1630-1730	86	82	26	15	0	
Day 7: Sat	0700-0800	125	115	13	6	0	
Average veh/hr		105	107	18	17	0	**248**
Pcu factor		1	1.5	2.0	2.3	3.7	
Average pcu/hr		105	161	36	40	0	**342**

Not 100% traffic is expected for every hour in a day, therefore the following assumptions were taken into consideration for the calculation of average daily traffic.

i. 2 peak hours with 100% traffic (0700-0800 and 1630-1730)
ii. 40% of the traffic for an approximation of 8.5 hours (0800-1630).
iii. 10% of traffic for an approximation of 13.5hours (1730-0700)

One-directional traffic = $\frac{342}{2} = 171$pcu/hr/lane

ADT = (171×1×2) + (171×0.4×8.5) + (171×0.1×13.5) = 1153pcu/day

$$AADT = ADT \times 365$$
$$= 1153 \times 365$$
$$= 420\ 845 pcu/year$$

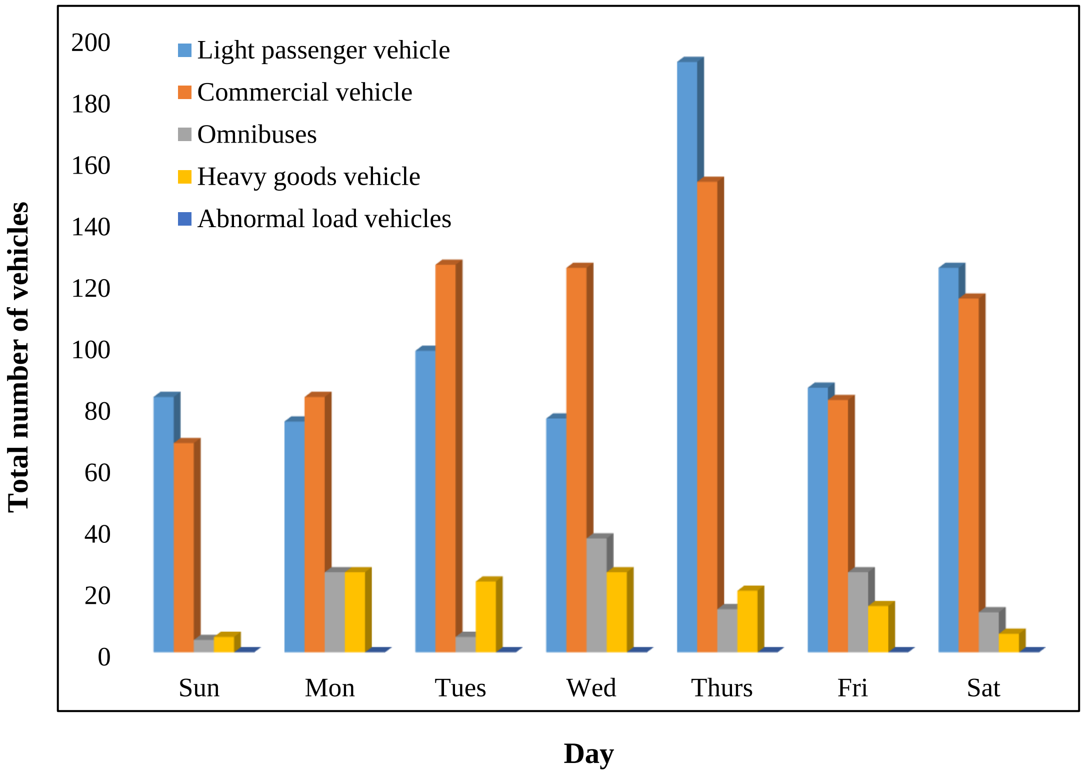


Figure 4.2: Composition of observed traffic.

Discussion

Figure 4.2 shows the composition and quantity of the observed traffic. No abnormal load vehicles passed on the road on any day during the traffic counting. Majority of the traffic was light passenger vehicles and commercial vehicles which are less than 2300kg in mass. Omnibuses and heavy goods trucks with a mass of more than 2300kg were comparatively few. The traffic is therefore described as E_1 (Committee of State Road Authorities, 1991).

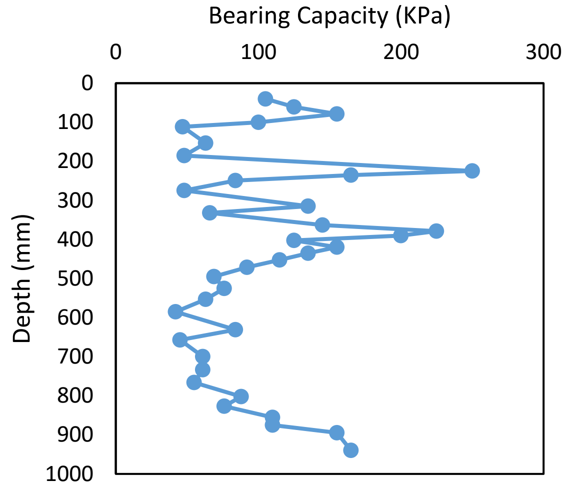
4.3 Geotechnical study

The results in the following sections are from in-situ and laboratory tests conducted on the existing material of the road.

4.3.1 Dynamic Cone Penetration test

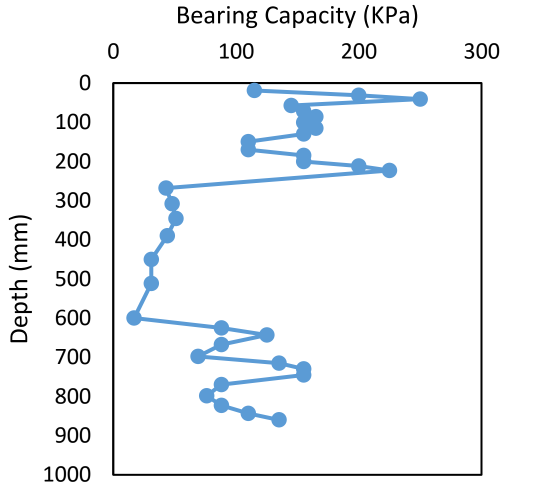
TP1

Variation of bearing capacity with depth.

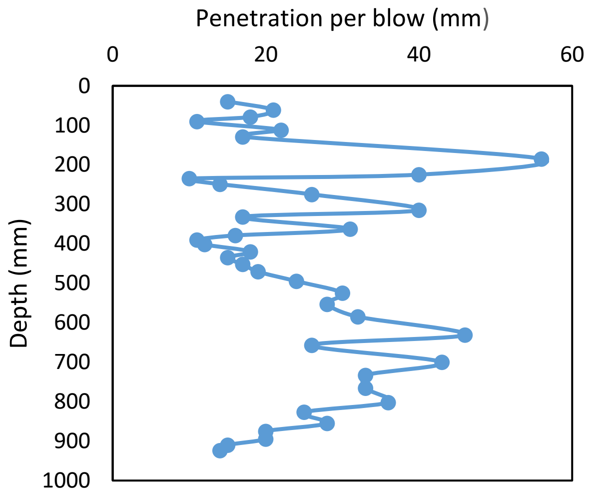


TP2

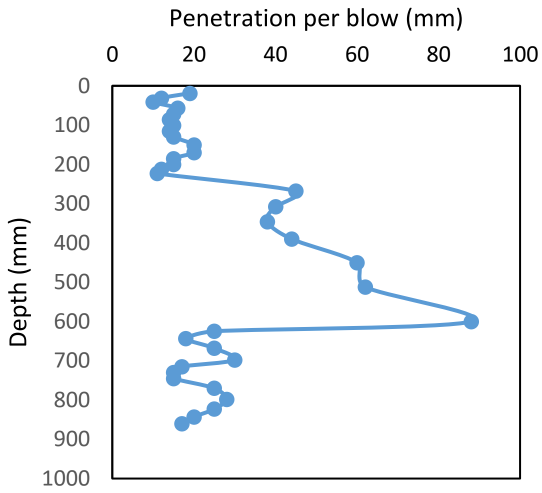
Variation of bearing capacity with depth.



Variation of penetration per blow with depth



Variation of penetration per blow with depth



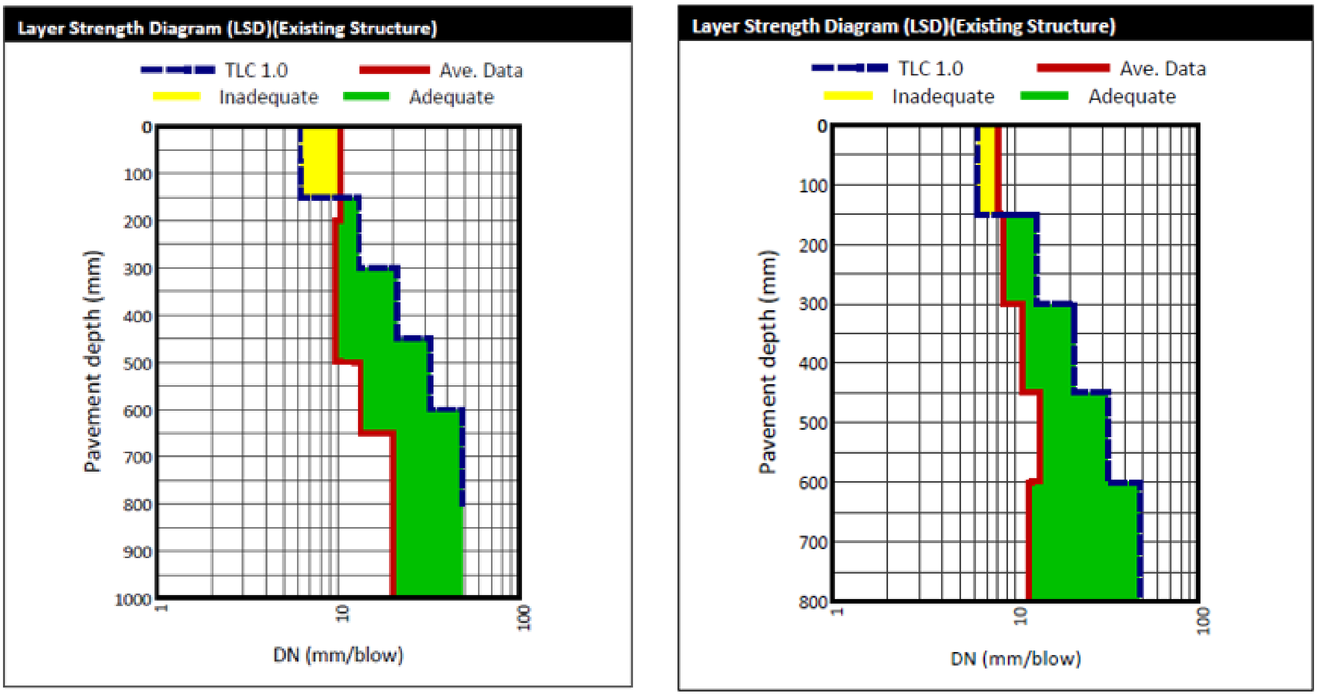


Figure 4.3: Graphs showing variation of in-situ strength with depth for each trial pit.

Discussion

The bearing capacity of the existing pavement generally increases with depth as shown in Figure 4.3. For trial pit 1, the DCP in-situ test was done on a heavily pothole damaged area which is why all the layers are relatively weak. According to layer strength diagrams, the layers for both trial pits are adequate to withstand traffic loading except for the 0-150mm layer which is inadequate. For trial pit 2, the DCP in-situ test was done on a section with cracks and no potholes which is the reason why from 270-630mm the layer is weak as shown by very low bearing capacity values of 20-50kPa. It is assumed that for outlier points on the graphs with relatively higher values of 250kPa, the DCP cone had encountered a stone within the existing material. The top layers of the pavement have low resistance which implies that the existing material must be improved by stabilisation techniques or it must be removed and replaced.

4.3.2 Soil profile

Table 4.6 shows the description of the soil profile noted after trial pits were dug on the edge of the road.

Table 4.6: Soil profile for the existing pavement of Chitungwiza road

Trial pit code	Depth (m)	Description (Colour, soil type)	Moisture Content	Profile image
TP1	0	Grass on shoulders	Moist	
	0 - 0.2	Imported brown gravel soil	Moist	
	0.2 - 0.5	Imported dark red gravel	Moist	
	0.5 - 0.65	Light grey silty sand soil	Moist	
	0.65 -1	Dense brown loam soil	Moist	
	>1	Black soil	Moist	
TP2	0	Eroded top soil on shoulders	Moist	
	0 - 0.2	Imported gravel	Moist	
	0.2 - 0.5	Light brown imported gravel	Moist	
	0.5 - 0.65	Silty grey soil	Moist	
	0.65 -1	Light brown loam soil	Moist	

4.3.3 Particle size distribution test

Figure 4.4 and 4.5 are particle size distribution curves for TP1 and TP2 at 0.5m and 1m depths. The values were found from the sieve and hydrometer analysis tests as well as the specific gravity test conducted in the laboratory. Detailed results are found in Appendix 4b.

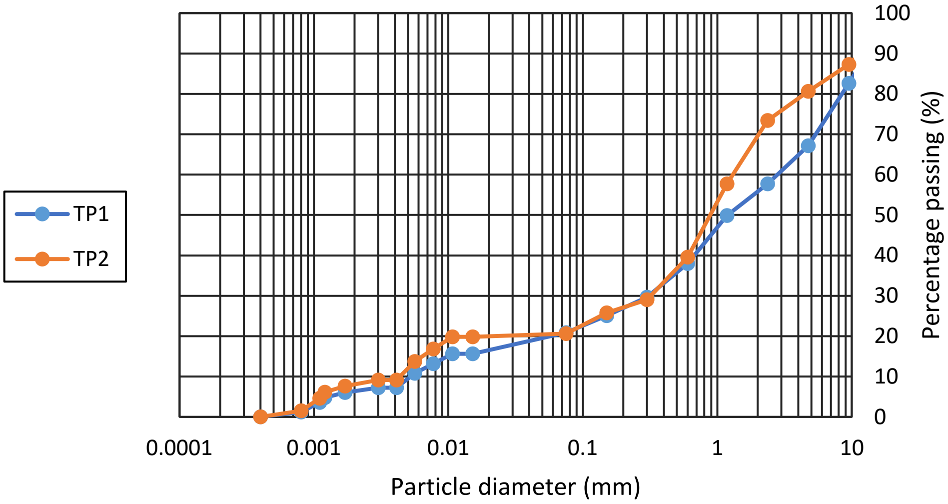


Figure 4.4: Particle size distribution curves for samples taken at 0.5m depth from both trial pits.

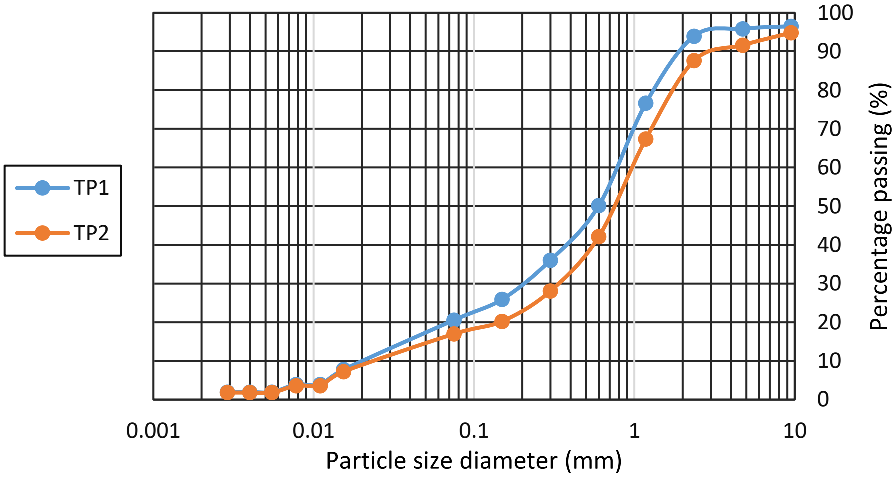


Figure 4.5: Particle size distribution curves for samples taken at 1m depth from both trial pits.

Discussion

Table 4.7: Coarseness and fineness index for TP1 and TP2.

Parameter	TP1		TP2	
	0.5m	1m	0.5m	1m
Coarseness index (100 - %passing 2.36mm sieve), %	**42.3**	**6.0**	**23.7**	**12.4**
Fineness index (% passing 0.075mm sieve)	**21.4**	**20.5**	**21.9**	**17.0**

Table 4.7 shows the results found from particle size distribution tests for both trial pits at different depths. The composition of the soil samples from both trial pits shows an insignificant variation as shown by the graph which indicates that the existing pavement had uniform soil type. At 0.5m depth, the curves show an even distribution of soil particle sizes therefore the soil is described as light brown clayey-gravel. At 1m depth, the soil is described as light grey slightly silty sand. Major component being sand. The soil is therefore deemed suitable for stabilisation with EarthZyme solution since the % passing 0.075mm BS sieve is greater than 20% except for soil sample collected from TP2 at 1m.

4.3.4 Atterberg limits

Atterberg limits test was conducted on two samples, for TP1 and TP2 at 0.5m depth. Samples at 1m depth were considered non-plastic according to the particle size distribution classification of the material for both trial pits. Sandy soils are cohesionless. Table 4.8 shows the description of material in terms of plasticity according to ranges of plasticity index value of the material.

Table 4.8: Plasticity description and range

Plasticity index	Description
0	Non-plastic
1-5	Slightly plastic
5-10	Low plasticity
10-20	Medium plasticity
20-40	High plasticity
>40	Very high plasticity

Table 4.9 shows summary of laboratory results for Atterberg limits tests. The plasticity index and liquid limit values were plotted on the Casagrande plasticity chart in order to classify the soil sample according to Unified Soil Classification System (USCS). Detailed results are presented in Appendix 4c.

Table 4.9: Summary of Atterberg limits results

Trial pit code	Depth (mm)	Liquid Limit, LL (%)	Plastic Limit, PL (%)	Plasticity Index, PI (%)	Soil Classification
TP1	0.5	20.3	5.1	13.8	Low plasticity
	1	-	-	-	Non-plastic
TP2	0.5	18.3	6.0	14.0	Low plasticity
	1	-	-	-	Non-plastic

Discussion

According to Table 4.9, the soil sample for TP1 and TP2 had; plasticity indices of 13.8 and 14; liquid limits of 20.3 and 18.3; and plastic limit of 5.1 and 6 respectively. According to the Casagrande plasticity chart, the soil is classified as CL group which represents clay of low plasticity. The plasticity index for both tests is greater than 8 which is required for suitability of soil to be stabilised by EarthZyme solution. The soil at 1.0m depth was classified as silty sand therefore literature reviews that either silt nor sand is non-plastic therefore Atterberg limits were carried out on the clayey-gravel sample collected at 0.5m depth.

4.3.5 Triaxial shear strength test

Figure 4.6 shows the compaction curve drawn during the determination of the optimum moisture content to use during triaxial test.

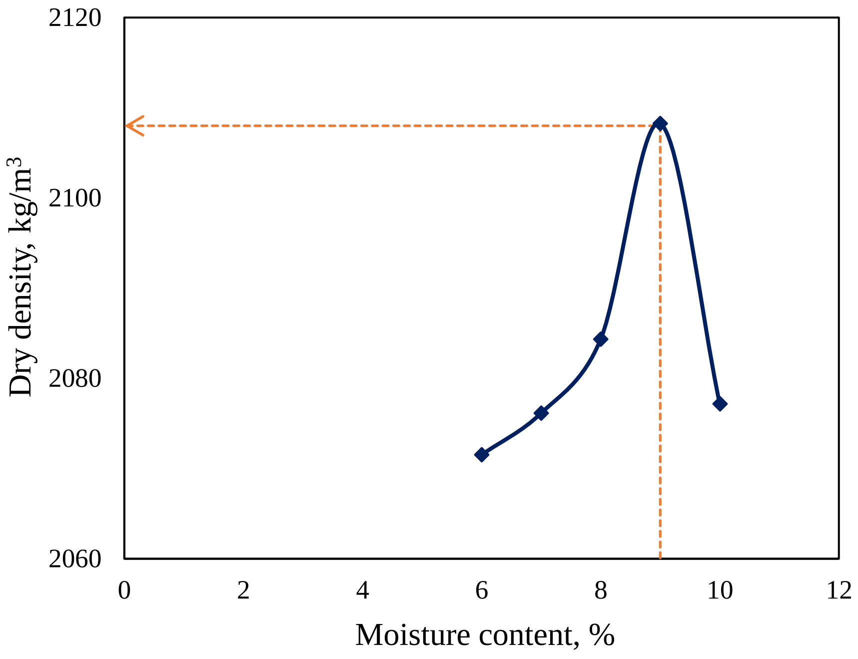


Figure 4.6: Compaction curve to determine optimum moisture content for triaxial test.

Analysis of results

MDD = 2108 kg/m^3, OMC = 9%

Using the OMC of 9%, 5 specimens were compacted and compressed. Table 4.10 shows summary of triaxial test results for the sample. Full detailed results are presented in Appendix 4d. Figure 4.7 shows the Mohr plot for the triaxial test conducted in the laboratory.

Table 4.10: Triaxial results.

Specimen number		**1**	**2**	**3**	**4**
Axial stress	σ_1	45	190	295	440
Cell pressure	σ_3	0	20	40	70
Radius	$(\sigma_1-\sigma_3)/2$	22.5	85	128	185
σ_{avg}	$(\sigma_1+\sigma_3)/2$	22.5	105	168	255

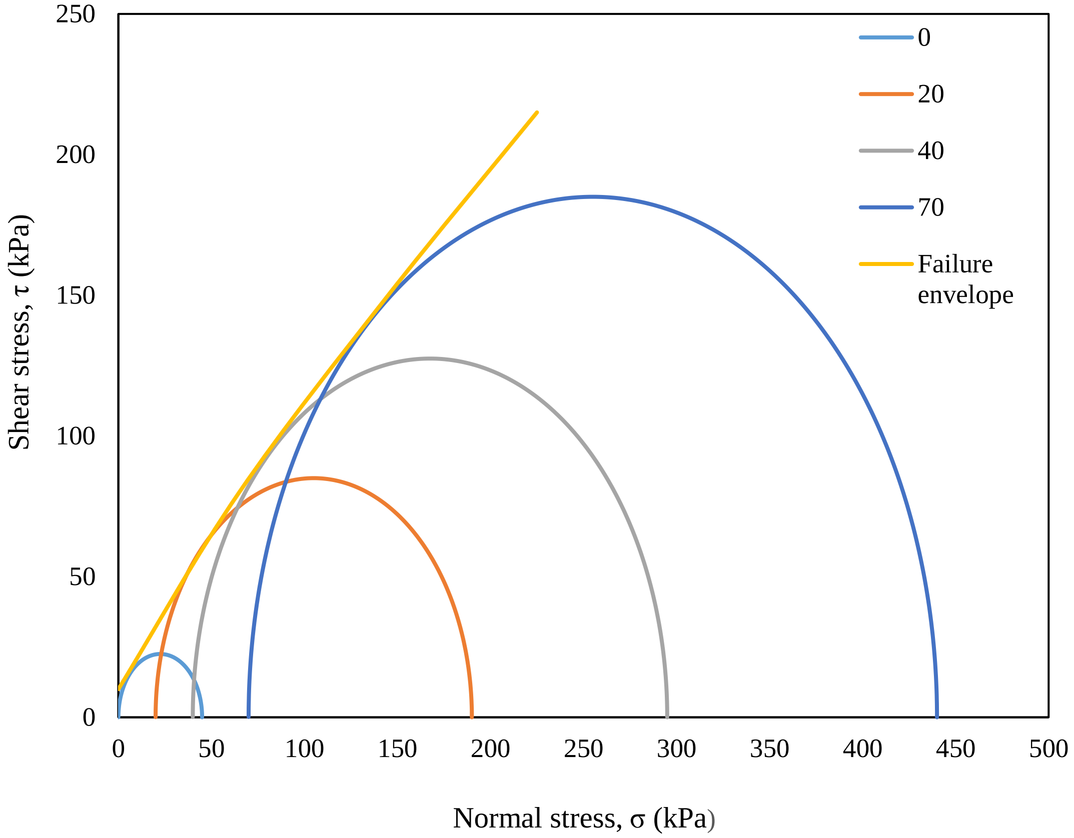


Figure 4.7: Mohr-Coulomb plot of triaxial test

Analysis and discussion of results

The failure envelope was reproduced on a Ministry of Transport triaxial classification chart as shown in Figure 4.8.

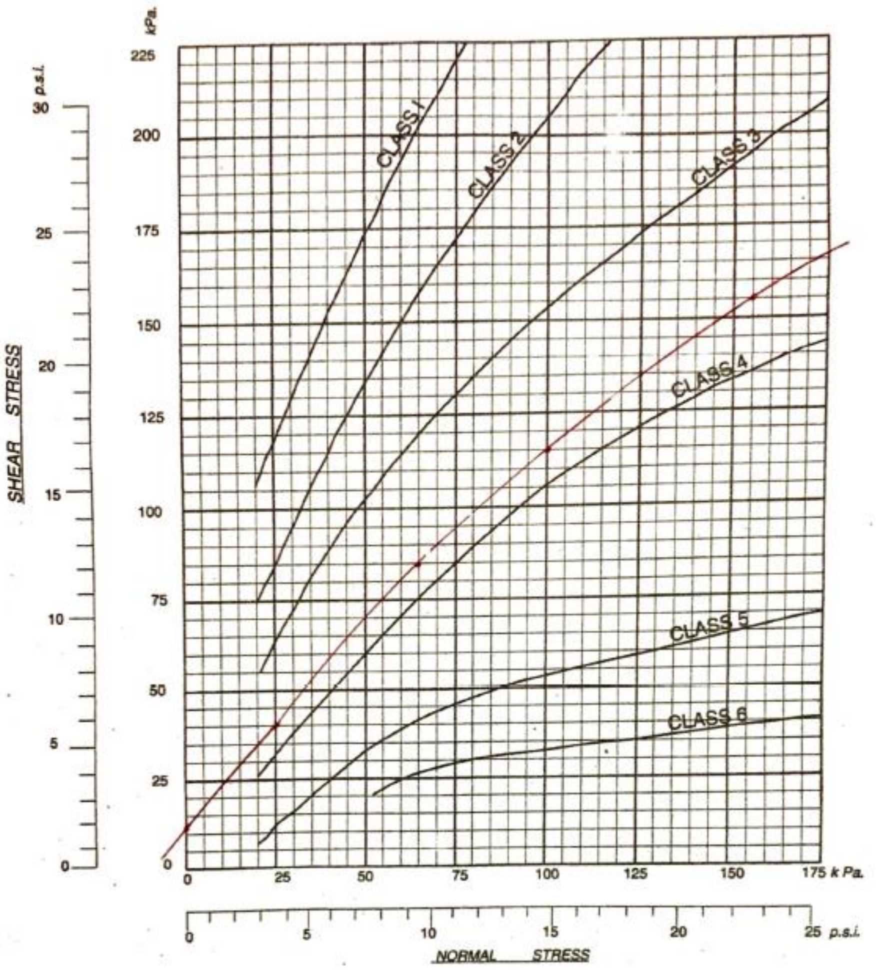


Figure 4.8: Ministry of Transport triaxial classification chart.

The triaxial class for the material was determined to be **class 3.7**. The soil sample is therefore classified as A-2-6 which represents a clayey gravel material according to AASHTO classification. Table 4.11 shows the shear strength parameters determined from the failure envelope.

Table 4.11: Shear strength parameters for natural material

Shear strength parameter	Calculation	Value
Cohesion, c	y-intercept	10
Frictional angle, Ø	$\tau_f = c + \sigma_f tan\emptyset$ $\emptyset = tan^{-}\left[\frac{(\tau_f - c)}{\sigma_f}\right]$ $\emptyset = tan^{-}(0.6) = 30.96$	31˚

4.3.6 Compaction test

Results obtained during compaction test are presented in Appendix 4e. These results were plotted on a graph shown in Figure 4.9 and the optimum moisture content was determined at maximum dry density.

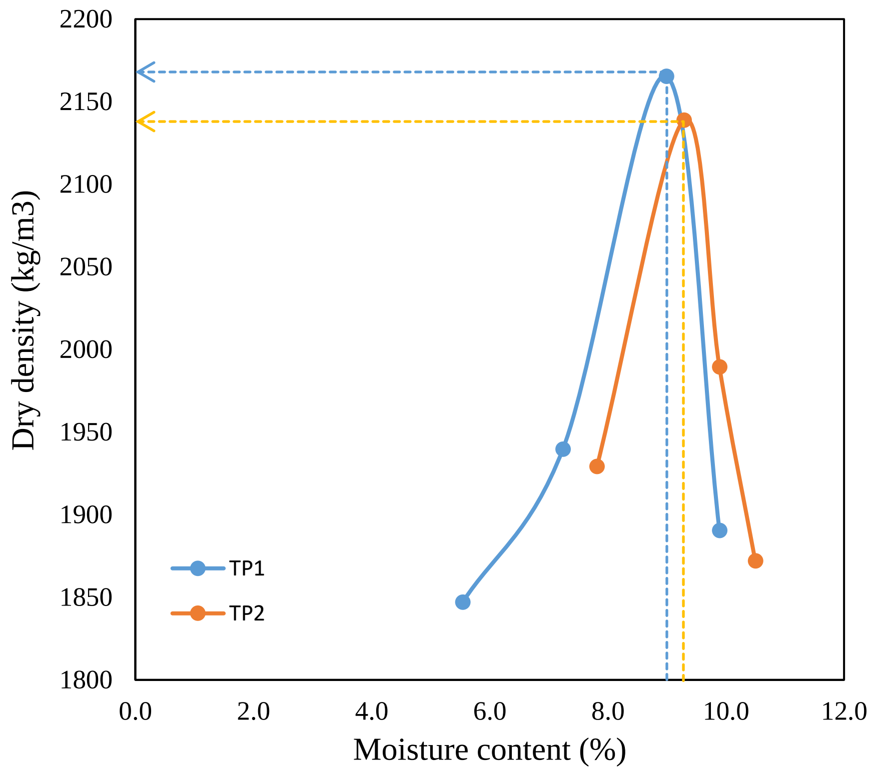


Figure 4.9: Graph showing variation of dry density with moisture content.

Discussion

According to the graph on Figure 4.9:

for trial pit 1, the Maximum Dry Density (MDD) =2165kg/m^3

Optimum Moisture Content (OMC) = 9.0%

for trial pit 2, the Maximum Dry Density = 2139kg/m^3

Optimum Moisture Content = 9.3%

These values, MDD and OMC, were used in the calculation of the amount of soil required per mould.

4.4 Material geotechnical investigations

The soil sample at 0.5m depth, having a plasticity index greater than 8 and fineness index of more than 20%, met the requirements for suitability of material to be stabilised with EZ stabiliser. The following calculations were done prior the stabilisation to determine the amount of stabiliser required per sample to be compacted.

Calculations:

Volume of mould = 2250ml (0.00225m^3)

From compaction test: Density of soil (MDD) =2165kg/m^3

Optimum Moisture Content (OMC) = 9.0%

$$\text{Amount of soil required per mould} = density\ of\ soil \times volume\ of\ mould \qquad \text{(Equation 6)}$$

$$= 2165 \times 0.00225 = 4.9\text{kg}$$

$$\approx 5000\text{g}$$

Amount of water to add:

i. **Water only:**

Mass of water = $OMC \times weight\ of\ dry\ soil$

$$= \frac{9}{100} \times 5000$$

$$= 450\text{g}$$

ii. **Water + EZ stabiliser:**

OMC is reduced by 2%.

Therefore, $OMC - 2 = 9 - 2$

= 7%

Mass of water = $\frac{7}{100} \times 5000$

= 350g

Ratio of stabiliser to amount of material is given as 1 litre of EZ for 33m^3 of compacted soil.

Mass of EarthZyme solution per mould = $volume\ of\ mould\ \times ratio$ *Equation 7*

= 30.3 × 0.00225

=0.681g

≈ 1ml

Table 4.12:Compaction quantitative details

Duration (days)	7			28		
Test	treated, dry	treated, soaked	untreated, soaked	treated, dry	treated, soaked	untreated, soaked
Mould number	86	51	57	26	18	54
Mass of empty mould (g)	3020	3060	3020	3000	3080	3080
Mass of empty mould + sample (g)	7840	7940	7980	7800	8000	8060
Mass of wet sample (g)	4820	4880	4960	4800	4920	4980
Mass of wet sample (kg)	4.820	4.880	4.960	4.800	4.920	4.980
Volume of EZ stabiliser added to water (ml)	1	1	0	1	1	0
Volume of water added to sample (ml)	350	350	450	350	350	450
OMC (%)	9.0	9.0	7.0	9.0	9.0	7.0

California bearing ratio test

The graphs, shown in Appendix 4f, for CBR penetration against load were convex curves therefore they were corrected to be concave. Maximum CBR values between 2.5mm and 5mm penetration were recorded as a percentage. Since optimum moisture content was used during compaction of the soil sample, the CBR values obtained are the design CBR.

Table 4.13: % CBR for untreated, treated, soaked and dry tests.

Test	7 days	28 days
Untreated, soaked CBR	20	22
Stabilised, soaked CBR	87	99
Stabilised, dry CBR	165	196

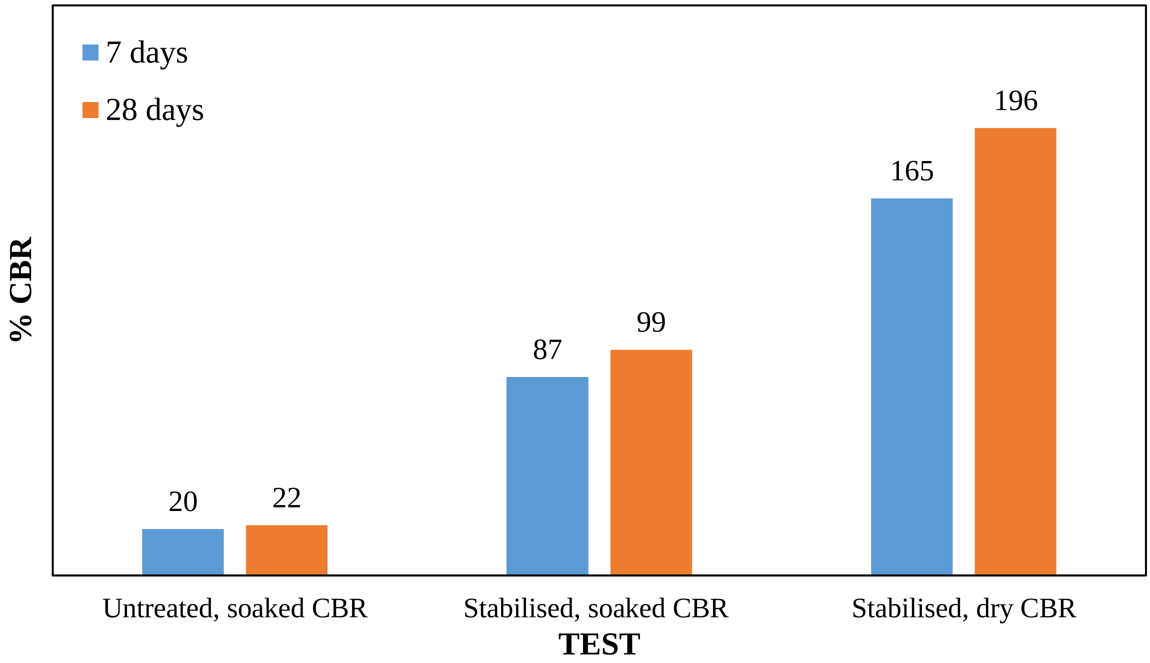


Figure 4.10: Variation of dry and soaked CBR tests for samples with and without stabiliser.

<u>Discussion</u>

According to Figure 4.10, the untreated material has a CBR of 20% and 22% at 7 and 28 days respectively. This test was done as a control test to note the change in strength between the untreated and treated specimen using % CBR values. CBR values increased when the soil was stabilised. A 77% CBR increase of the treated soil sample as compared to the untreated specimen was observed which is evidence that the stabiliser is efficient.

For soaked CBR, the sample was exposed to worst conditions which is the reason why these values were comparatively less than those for dry CBR test. The maximum CBR of the treated soil sample under worst conditions is 99%, obtained on day 28. CBR value increased from 87% on day 7 to 99% on day 28, therefore there is gradual strength development with time which supports the fact that one strength of EarthZyme road stabiliser is it bio-degrades over a period of 28 days and a gradual increase in strength of the stabilised soil is developed. The maximum untreated in-situ, dry CBR value of the existing material was 20% and 22% for TP1 and TP2. Dry CBR for treated specimen increased to 165% and 196 %, respectively, which shows that under best conditions EarthZyme solution is very effective.

Having a minimum CBR value of 20%, the material in its natural state is classified as a G6 gravel material (Committee of Transport Officials, 2020). The treated material had a minimum soaked CBR value of 87% therefore the material suitable to be used in construction of the road's base layer (SATCC, 1998).

Chapter 5

5.0 Pavement rehabilitation design

This chapter presents the pavement design for the 2km section of Chitungwiza road rehabilitation program.

5.1 Traffic loading

The traffic load for the road is determined in the following sections.

5.1.1 Cumulative design traffic

The cumulative design traffic is calculated as follows.

$$Cumulative\ design\ traffic, DT = ADT \times 365 \times growth\ factor$$

i. Calculation of Average Daily Traffic, ADT, considering vehicles which are classified as ESA according to Ministry of Transport and Energy, (1989b).

One-directional traffic = $\frac{75}{2}$

= **38pcu/hr/lane**

Therefore, *ADT* = (38×1×2) + (38×0.4×8.5) + (38×0.1×13.5)

= **257pcu/day**

ii. The following assumptions were made according to Ministry of Transport and Energy, (1989b).
   - Design life = 20 years
   - Growth rate = 5% per annum

$$Growth\ factor = \frac{[(1+r)^{n} - 1]}{r}$$

where r = growth rate as a decimal.

n = design life in years.

$$Growth\ factor = \frac{[(1+0.05)^{20} - 1]}{0.05}$$

= **33**

$$DT = 257 \times 365 \times 33$$

$$= 3\ 095\ 565$$

5.1.2 Cumulative design ESA load

Using the following equations, Table 5.1 presents the calculation of cumulative equivalent standard axles for Chitungwiza road.

$$Equivalency\ Factor, EF = \left[\frac{L}{8.2}\right]^n$$

where, L is axle load in tonnes and n = 4.5

$$Design\ ESA = EF \times DT$$

Table 5.1: Calculation of cumulative design ESA load

Vehicle type	Mass	EF	Design ESA
Omnibuses	3000kg (3tonnes)	$EF = \left[\frac{3}{8.2}\right]^{4.5}$ = 0.01	$Design\ ESA = 0.01 \times 3\ 095\ 565$ = **30 956**
Heavy goods vehicles	6000kg (6tonnes)	$EF = \left[\frac{6}{8.2}\right]^{4.5}$ = 0.24	$Design\ ESA = 0.24 \times 3\ 095\ 565$ $= \mathbf{742\ 936}$
$Cumulative\ Design\ ESA$			773 892 ≈ **0.8 M ESA**

According to Table 2.6, the traffic class for Chitungwiza road is T3 since the traffic range is between 0.7 and 1.5 million ESA.

5.2 Chitungwiza flexible pavement design

Table 5.2 shows the step-by-step procedure which was used to come up with the flexible pavement design for the 2km section of Chitungwiza road.

Table 5.2: Pavement design proceedings (Author)

Reference	Calculations	Output
Ministry of Transport, 1989 Construction Manual Part F and SATCC, 1998.	**Assumptions:** a. The road will to be built starting on existing subgrade. Soil data obtained from the samples taken at 0.5 m and 1m depth are shown in Appendix 4. b. The traffic growth rate of 5 % per annum was used. c. The climatic adjustment factor is 1.0 d. The design life of the road is 20 years. e. The road will have two 3.5m-wide surfaced lanes and 1.0m unpaved shoulders both sides.	
Ministry of Transport, 1989, Traffic Manual Part K	**Traffic analysis:** Calculation done in Section 4.2 and 5.1.	**0.8M ESA** Therefore, pavement classification is in the 1M group.
Figure 3.7 Soil analysis from section 4.3 and 4.4. COTO, 2020. Clause A4.1.5: Material specifications. Overseas Road Note 3, 2000. Clause 2.3 Ministry of Transport, 1989, Construction Manual Part F, clause 10.11.5	**Structure of pavement:** 1. Road bed, in-situ material. 2. Selected subgrade – 150mm SG15/S5 material of class 3.9 or better with CBR > 15%, compacted at 93% Mod AASHTO density. 3. Base layers: i. Base 2 – 120mm stabilised sub-base, G6 gravel material of class 3.3 or better with CBR > 80%, compacted at 95% Mod AASHTO density. ii. Base 1 – 150mm crushed stone base, G1 material of class 2.4 or better with CBR > 102%, compacted at 100% Mod AASHTO density. 4. Surfacing – double seal dressing. Tar prime coat, TP7. Aggregate size of 19mm and 13.2mm for tack and seal, respectively.	

SATCC (1998), Section 2102	70/100 penetration grade bitumen. Seal aggregate should be precoated. 5. Drainage for the road is provided by surface camber leading the water to side drains. A camber of 2% on traffic lanes and 4% on shoulders was adopted. Trapezoidal shaped side drains have a side slope of 1:2. 6. Erosion control – Vegetation unless otherwise construction of bolsters on naturally steep slopes.	
SATCC (1998)	**<u>Drawings:</u>** Long and cross-sectional drawings for the proposed pavement design were made in AutoCAD Civil 3D (2016), and AutoCAD (2022), respectively. Design speed: 60km/hr	See drawings in Appendix 5. See road elevations data in appendix 8.
Cypher environment, 2022 for EarthZyme calculation. Existing pavement data for cement calculation.	**<u>Determination of Material Volumes</u>** Volume of the materials to be imported to site was determined for the purposes of project cost estimation and analysis. Stabilisation materials i. EarthZyme solution: **60 litres** ii. Cement: **86 tonnes** The compacted volume of the pavement layers is multiplied with a factor of 1.3 to determine the uncompacted volume used in preparing the BOQs. Crushed stone volume: **2 964m^3**	Calculations shown in Appendix 6

Chapter 6

6.0 Cost analysis

This chapter presents Bill of Quantities for 2 designs, one includes EarthZyme solution stabilisation and the other, the conventional method of cement stabilisation. A cost comparative schedule of the 2 designs is done to ascertain an economic design for the rehabilitation program.

6.1 Cost evaluation for design with EarthZyme stabilisation

Table 6.1 shows the cost summary which encompasses every section of the BoQ shown in Appendix 7A. Preparation of the BoQ was based on proposed design information presented in Chapter 5.

Table 6.1: Summary of the BoQ for the design which incorporates stabilisation with EZ

SECTION	DESCRIPTION	AMOUNT (US$)
1000	GENERAL	83 137.92
2000	DRAINAGE	59 701.56
3000	EARTHWORKS AND PAVEMENT LAYERS OF GRAVEL AND CRUSHED STONE	109 051.20
4000	SEALS	205 800.00
5000	ANCILLARY ROADWORKS	32 700.60
	SUB TOTAL [excluding VAT]	**490 391.28**
	ADD 20% CONTINGENCY SUM	98 078.26
	SUB TOTAL	**588 469.54**
	ADD 15% VAT	88 270.43
	TOTAL COST	**676 740.00**

6.2 Cost evaluation for conventional design with cement stabilisation

Table 6.2 shows the cost summary which encompasses every section of the BoQ shown in Appendix 7B. Preparation of the BoQ was based on design information of the existing pavement which is the conventional method for road construction.

Table 6.2: Summary of the BoQ for the design which includes cement stabilisation.

SECTION	DESCRIPTION	AMOUNT (US$)
1000	GENERAL	85 397.92
2000	DRAINAGE	59 701.56
3000	EARTHWORKS AND PAVEMENT LAYERS OF GRAVEL AND CRUSHED STONE	154 239.52
4000	SEALS	205 800.00
5000	ANCILLARY ROADWORKS	32 700.60
	SUB TOTAL [excluding VAT]	**537 839.60**
	ADD 20% CONTINGENCY SUM	107 567.92
	SUB TOTAL	**645 407.92**
	ADD 15% VAT	96 811.13
	TOTAL COST	**742 218.60**

6.3 Cost comparison

Incorporating EZ stabilisation in pavement design for 2km Chitungwiza road rehabilitation program reduced the construction costs by **10%** from US$ 742 218.60 to US$ 676 740.00. This difference is mainly because for stabilisation with EZ solution, gravel from existing layer material is to be used whereas for the conventional method of cement stabilisation gravel is imported from an approved borrow pit. It is also because EZ road stabiliser is less bulky as compared to cement. EZ solution is diluted in water whereas cement is blended with the gravel material.

CHAPTER 7

7.0 CONCLUSION AND RECOMMENDATIONS

Conclusion

The study presents a proposed design of a 2km flexible pavement which is 7/9m wide with 2 new bases, granular for Base 1 and stabilised for Base 2, and a double dressing seal for Chitungwiza road rehabilitation program. In terms of effectiveness, the soaked CBR results for stabilised specimen showed a 77% increase in strength from the untreated soaked CBR results. Since EarthZyme solution alters the clay content in soil, it is important to determine the clay content in a soil sample before stabilisation proceeds otherwise there is need to blend the soil with clay for better results. It is evident that treated specimen increased strength on day 28 as compared to day 7 based on the CBR test results which means strength development gradually continues with time. There is also a 10% reduction in construction costs for the design which includes Base 2 stabilisation with EarthZyme solution compared to the design which includes the conventional method of cement stabilisation hence its economic. Since EZ is a liquid, dust is eliminated in construction zones. Ultimately, EarthZyme solution is feasible for use as a sustainable road stabiliser in pavement construction.

Recommendations

1. A 200m trial section should be done on site to fully ascertain the effectiveness of implementing the stabilisation method and assessed over time whilst exposed to site conditions as well as traffic loading.
2. The use of EarthZyme solution as a sustainable road stabiliser in road construction is effective provided the material to be stabilised meets the compatibility requirements therefore, the author recommends the Ministry of Transport and Infrastructure to consider its implementation.
3. A sample of EarthZyme solution should be taken to XRF department to determine the chemical properties of the stabiliser to fully confirm the non-toxicity and non-leachability of the stabiliser.
4. Since there is construction of Mbudzi Interchange, in-depth research on existing traffic counts data is recommended for the rehabilitation design and include traffic growth adjustment factors.

5. Further research needs to be done for new product development since we have vast sugarcane plantations in Chiredzi Triangle.

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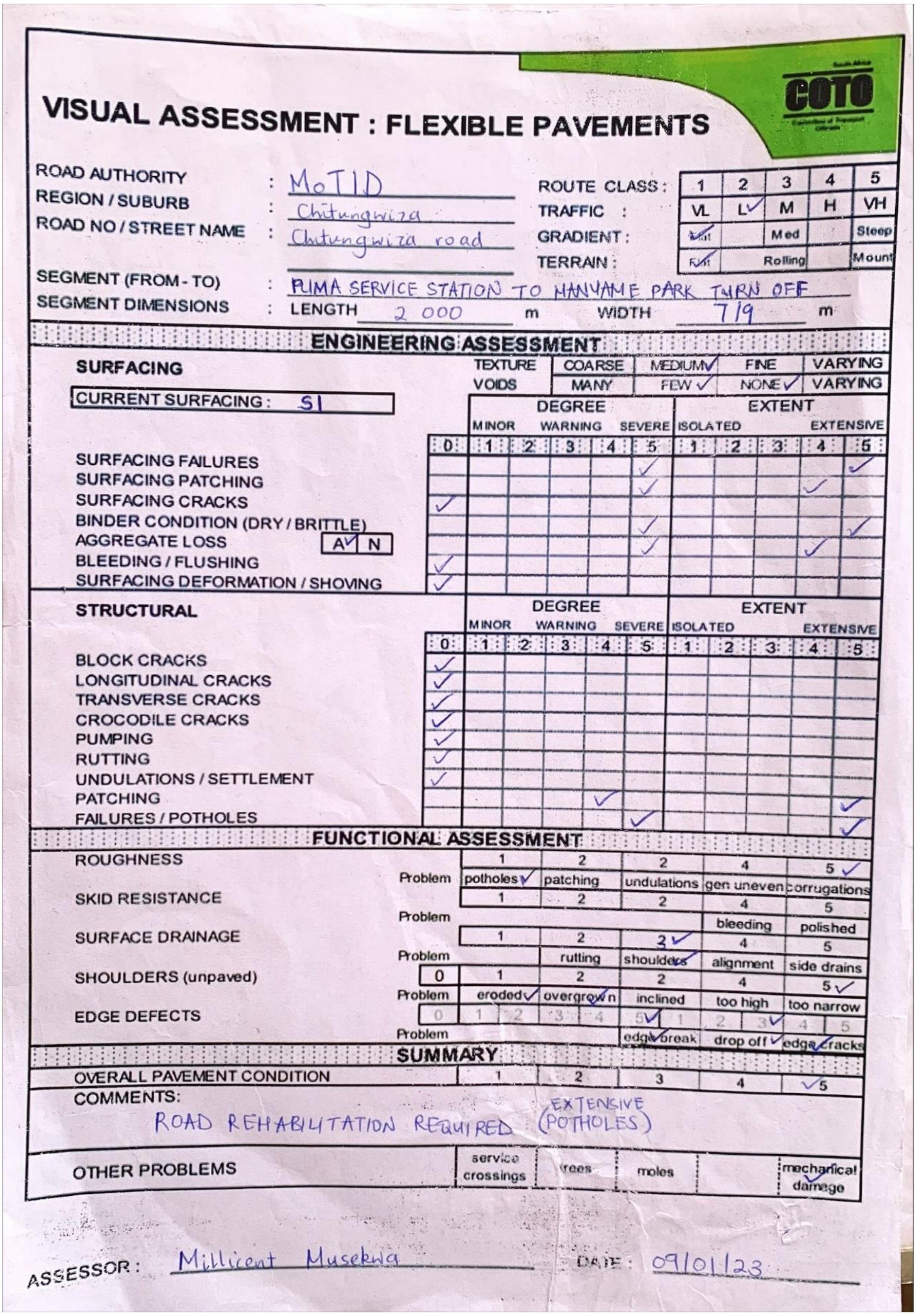
APPENDICES

Appendix 1: Visual assessment form



VISUAL ASSESSMENT : FLEXIBLE PAVEMENTS COTO

ROAD AUTHORITY	: MoTID	ROUTE CLASS :	1	2	3	4	5
REGION / SUBURB	: Chitungwiza	TRAFFIC :	VL	L✓	M	H	VH
ROAD NO / STREET NAME	: Chitungwiza road	GRADIENT :	Flat✓		Med		Steep
		TERRAIN :	Flat✓		Rolling		Mount

SEGMENT (FROM - TO) : PUMA SERVICE STATION TO MANYAME PARK TURN OFF

SEGMENT DIMENSIONS : LENGTH 2 000 m WIDTH 7.9 m

ENGINEERING ASSESSMENT

SURFACING

TEXTURE	COARSE	MEDIUM✓	FINE	VARYING
VOIDS	MANY	FEW ✓	NONE ✓	VARYING

CURRENT SURFACING : S1

	0	DEGREE: MINOR 1	2	WARNING 3	4	SEVERE 5	EXTENT: ISOLATED 1	2	3	4	EXTENSIVE 5
SURFACING FAILURES						✓					✓
SURFACING PATCHING						✓				✓	
SURFACING CRACKS	✓										
BINDER CONDITION (DRY / BRITTLE)						✓					✓
AGGREGATE LOSS (A✓ N)						✓				✓	
BLEEDING / FLUSHING	✓										
SURFACING DEFORMATION / SHOVING	✓										

STRUCTURAL

	0	DEGREE: MINOR 1	2	WARNING 3	4	SEVERE 5	EXTENT: ISOLATED 1	2	3	4	EXTENSIVE 5
BLOCK CRACKS	✓										
LONGITUDINAL CRACKS	✓										
TRANSVERSE CRACKS	✓										
CROCODILE CRACKS	✓										
PUMPING	✓										
RUTTING	✓										
UNDULATIONS / SETTLEMENT	✓										
PATCHING					✓						✓
FAILURES / POTHOLES						✓					✓

FUNCTIONAL ASSESSMENT

ROUGHNESS		1	2	2	4	5 ✓
	Problem	potholes ✓	patching	undulations	gen uneven	corrugations
SKID RESISTANCE		1	2	2	4	5
	Problem				bleeding	polished
SURFACE DRAINAGE		1	2	3 ✓	4	5
	Problem		rutting	shoulders ✓	alignment	side drains
SHOULDERS (unpaved)	0	1	2	2	4	5 ✓
	Problem	eroded ✓	overgrown ✓	inclined	too high	too narrow
EDGE DEFECTS	0	1 2	3 4	5 ✓ 1	2 3 ✓	4 5
	Problem			edge break ✓	drop off ✓	edge cracks ✓

SUMMARY

OVERALL PAVEMENT CONDITION	1	2	3	4	✓ 5

COMMENTS: ROAD REHABILITATION REQUIRED (EXTENSIVE POTHOLES)

OTHER PROBLEMS	service crossings	trees	moles		mechanical damage

ASSESSOR : Millicent Musekwa DATE : 09/01/23

Appendix 2: Pictures taken during visual assessment of Chitungwiza road.

Overgrown vegetation on shoulders

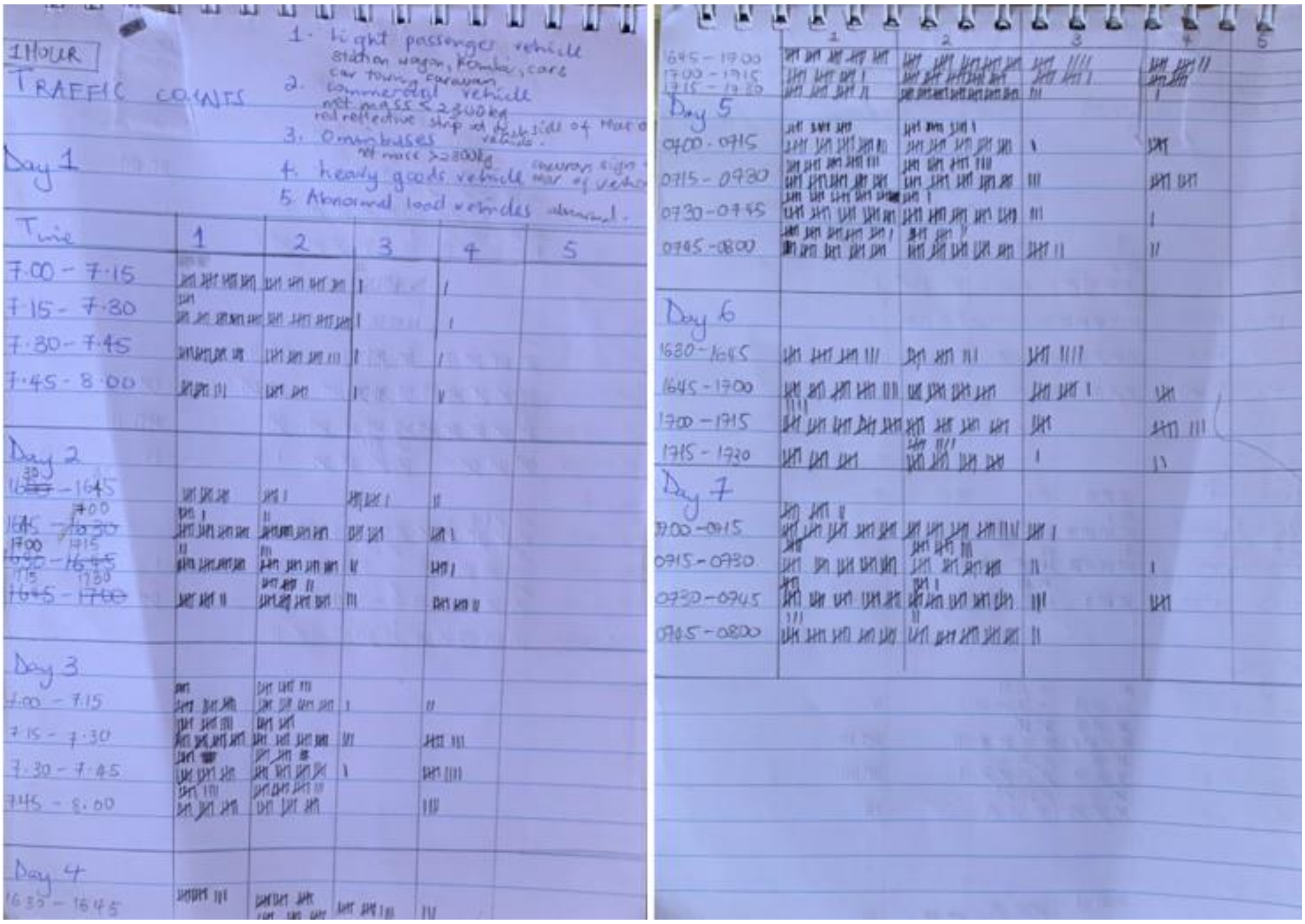
Edge defects and potholes

Edge cracks

Surface failures (Aggregate loss and potholes)

Surface patching with asphalt and with gravel

Appendix 3: Traffic counts



Day	Time	Light passenger vehicle	Commercial vehicle	Omnibuses	Heavy goods vehicle	Abnormal load vehicles
Day 1: 29.01.23 (Sun)	0700-0715	20	20	1	1	0
	0715-0730	30	20	1	1	0
	0730-0745	20	18	1	1	0
	0745-0800	13	10	1	2	0
Day 2: 30.01.23 (Mon)	1630-1645	15	6	11	2	0
	1645-1700	26	22	10	6	0
	1700-0715	22	23	2	6	0
	1715-1730	12	32	3	12	0
Day 3: 31.01.23 (Tue)	0700-0715	20	33	1	2	0
	0715-0730	34	30	3	8	0
	0730-0745	20	30	1	9	0
	0745-0800	24	33	0	4	0
Day 4: 01.02.23 (Wed)	0700-0715	18	40	14	3	0
	0715-0730	25	25	9	12	0
	0730-0745	16	25	11	10	0
	0745-0800	17	35	3	1	0
Day 5: 02.02.23 (Th)	1630-1645	38	41	1	5	0
	1645-1700	48	44	3	10	0
	1700-1715	55	31	3	3	0
	1715-1730	51	37	7	2	0
Day 6: 03.02.23 (Fri)	1630-1645	18	13	9	0	0
	1645-1700	24	20	11	5	0
	1700-1715	29	20	5	8	0
	1715-1730	15	29	1	2	0
Day 7: 04.02.23 (Sat)	0700-0715	37	24	6	0	0
	0715-0730	30	33	2	1	0
	0730-0745	30	31	3	5	0
	0745-0800	28	27	2	0	0

Appendix 4: Geotechnical investigations

TABLES, CALCULATIONS AND PICTURES.

4a. Dynamic cone penetrometer results

Trial Pit 1

N	DCP scale reading	Penetration per blow	Equivalent bearing pressure	Equivalent CBR (%)	N	DCP scale reading	Penetration per blow	Equivalent bearing pressure	Equivalent CBR (%)
0	25				3	435	15	155	14
1	40	15	155	14	3	452	17	135	12
1	61	21	105	10	3	471	19	115	11
1	79	18	125	12	3	495	24	92	9
1	90	11	155	14	3	525	30	69	6
2	112	22	100	10	3	553	28	76	7
2	129	17	135	12	3	585	32	63	6
3	185	56	63	6	3	631	46	42	4
3	225	40	48	4	1	657	26	84	8
1	235	10	250	22	1	700	43	45	4
2	249	14	165	16	1	733	33	61	6
5	275	26	84	8	1	766	33	61	6
5	315	40	48	4	1	802	36	55	6
3	332	17	135	12	1	827	25	88	8
3	363	31	66	6	1	855	28	76	7
4	379	16	145	13	1	875	20	110	10
2	390	11	225	20	1	895	20	110	10
2	402	12	200	18	2	940	45	43	4
4	420	18	125	12	2	955	15	155	14

Trial Pit 2

N	DCP scale reading	Penetration per blow	Equivalent bearing pressure	Equivalent CBR (%)	N	DCP scale reading	Penetration per blow	Equivalent bearing pressure	Equivalent CBR (%)
0	0				3	320	5	155	14
1	3	3	155	14	3	327	7	135	12
1	20	17	105	10	3	333	6	115	11
1	35	15	125	12	3	355	22	92	9
1	55	20	155	14	3	383	28	69	6
2	72	17	100	10	3	375	-8	76	7
2	95	23	135	12	3	395	20	63	6
3	130	35	63	6	3	440	45	42	4
3	176	46	48	4	2	454	14	84	8
3	210	34	250	22	2	500	46	45	4
3	220	10	165	16	2	555	55	61	6
5	239	19	84	8	1	581	26	61	6
5	255	16	48	4	1	601	20	55	6
5	265	10	135	12	1	614	13	88	8
5	273	8	66	6	1	650	36	76	7
5	280	7	145	13	1	740	90	110	10
4	295	15	225	20	1	789	49	110	10
4	309	14	200	18	2	801	12	43	4
4	315	6	125	12	2	820	19	155	14

4b. Sieve and hydrometer analysis, specific gravity.

Table 4 Values of K^* for use in Eq. (6-9a) for several unit weights of soil solids and temperature combinations

Temp., °C	G_s of Soil Solids							
	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.0151	0.0148	0.0146	0.0144	0.0141	0.0139	0.0137	0.0136
17	0.0149	0.0146	0.0144	0.0142	0.0140	0.0138	0.0136	0.0134
18	0.0148	0.0144	0.0142	0.0140	0.0138	0.0136	0.0134	0.0132
19	0.0145	0.0143	0.0140	0.0138	0.0136	0.0134	0.0132	0.0131
20	0.0143	0.0141	0.0139	0.0137	0.0134	0.0133	0.0131	0.0129
21	0.0141	0.0139	0.0137	0.0135	0.0133	0.0131	0.0129	0.0127
22	0.0140	0.0137	0.0135	0.0133	0.0131	0.0129	0.0128	0.0126
23	0.0138	0.0136	0.0134	0.0132	0.0130	0.0128	0.0126	0.0124
24	0.0137	0.0134	0.0132	0.0130	0.0128	0.0126	0.0125	0.0123
25	0.0135	0.0133	0.0131	0.0129	0.0127	0.0125	0.0123	0.0122
26	0.0133	0.0131	0.0129	0.0127	0.0125	0.0124	0.0122	0.0120
27	0.0132	0.0130	0.0128	0.0126	0.0124	0.0122	0.0120	0.0119
28	0.0130	0.0128	0.0126	0.0124	0.0123	0.0121	0.0119	0.0117
29	0.0129	0.0127	0.0125	0.0123	0.0121	0.0120	0.0118	0.0116
30	0.0128	0.0126	0.0124	0.0122	0.0120	0.0118	0.0117	0.0115

* Units for K: $mm\left(\frac{min}{cm}\right)^{1/2}$

Table 5 Values of L (effective depth) for use in Stokes' formula for diameters of particles for ASTM soil hydrometer 152H

Original hydrometer reading (corrected for meniscus only)	Effective depth L, cm	Original hydrometer reading (corrected for meniscus only)	Effective depth L, cm	Original hydrometer reading (corrected for meniscus only)	Effective depth L, cm
0	16.3	21	12.9	42	9.4
1	16.1	22	12.7	43	9.2
2	16.0	23	12.5	44	9.1
3	15.8	24	12.4	45	8.9
4	15.6	25	12.2	46	8.8
5	15.5	26	12.0	47	8.6
6	15.3	27	11.9	48	8.4
7	15.2	28	11.7	49	8.3
8	15.0	29	11.5	50	8.1
9	14.8	30	11.4	51	7.9
10	14.7	31	11.2	52	7.8
11	14.5	32	11.1	53	7.6
12	14.3	33	10.9	54	7.4
13	14.2	34	10.7	55	7.3
14	14.0	35	10.5	56	7.1
15	13.8	36	10.4	57	7.0
16	13.7	37	10.2	58	6.8
17	13.5	38	10.1	59	6.6
18	13.3	39	9.9	60	6.5
19	13.2	40	9.7		
20	13.0	41	9.6		

Wet sieving

	TP1@0.5m	TP1@0.5m	TP1@0.5m	TP1@0.5m
Mass of dry sample before washing	500	500	500	500
Mass of dry sample after washing	419.09	400.33	414.21	422.25
Mass of washed away sample (-0.075W)	80.91	99.67	85.79	77.75

Specific gravity

	TP1 @ 0.5m		TP2 @ 0.5m	
Density bottle number	**163**	**193**	**39**	**31**
Mass of density bottle, M_1 (g)	36.28	36.51	32.93	32.72
Mass of bottle + dry soil(g), M_2 (g)	47.55	47.75	41.31	43.34
Mass of bottle+ soil +water, M_3 (g)	92.49	92.86	88.35	88.59
Mass of bottle + water only, M_4 (g)	85.53	85.94	83.14	82.03
Specific Gravity	2.61	2.60	2.64	2.62
Average specific gravity	2.61		2.63	

Specific Gravity $= \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)}$

For 163bottle $= \frac{47.55-36.28}{(85.53-36.28)-(92.49-47.55)}$

$=2.61$

TP1 at 0.5m

BS Sieve (mm)	Mass retained (g)	Percentage Retained (%)	Percentage Passing (%)
19	7.3	1.46	98.54
9.5	87.83	17.57	80.97
4.75	65.02	13.01	67.97
2.36	51.27	10.25	57.72
1.18	39.03	7.81	49.91
0.6	53.38	10.68	39.23
0.3	45.52	9.10	30.13
0.15	25.08	5.02	25.11
0.075	18.16	3.63	21.48
-0.075T	107.41	21.48	

Elapsed Time, t (min)	Temp (°C)	Hydrometer reading	Composite Correction	Corrected Reading (Rh1 = Rh-CC)	P% Finer than	P1% Finer than	Rh –Cm	Effective depth from table 5 (mm)	K values from table 4	Particle Diameter, D (mm)
1	26	17	4	13	27.04	15.61	15	13.5	0.013036	0.0151
2	26	17	4	13	27.04	15.61	15	13.5	0.013036	0.0107
4	26	15	4	11	22.88	13.21	13	13.8	0.013036	0.0077
8	25	13	4	9	18.72	10.80	11	14.2	0.013186	0.0056
15	25	10	4	6	12.48	7.20	8	14.7	0.013186	0.0041
30	24	10	4	6	12.48	7.20	8	14.7	0.01336	0.003
90	24	9	4	5	10.40	6.00	7	14.8	0.01336	0.0017
180	24	8	4	4	8.32	4.80	6	15	0.01336	0.0012
240	24	7	4	3	6.24	3.60	5	15.2	0.01336	0.0011
480	24	5	4	1	2.08	1.20	3	15.5	0.01336	0.0008
1440	24	4	4	0	0.00	0.00	2	15.6	0.01336	0.0004

TP1@ 1m

BS Sieve (mm)	Mass retained (g)	Percentage Retained (%)	Percentage Passing (%)
19	16.01	3.20	96.80
9.5	1.57	0.31	96.48
4.75	3.07	0.61	95.87
2.36	9.51	1.90	93.97
1.18	86.83	17.37	76.60
0.6	132.35	26.47	50.13
0.3	70.46	14.09	36.04
0.15	50.52	10.10	25.94
0.075	26.86	5.37	20.56
-0.075T	102.82	20.56	

Elapsed Time, t (min)	Temp (°C)	Hydrometer Reading (Rh)	Composite Correction (CC)	Corrected Reading (Rh1 = Rh-CC)	P% Finer than	P1% Finer than	Rh – Cm	Effective depth from table 5 (mm)	K values from table 4	Particle Diameter, D (mm)
1	24	8	4	4	8.29	7.79	6	15.0	0.01258	0.0154
2	24	6	4	2	4.14	3.89	4	15.3	0.01258	0.0110
4	24	6	4	2	4.14	3.89	4	15.3	0.01258	0.0078
8	24	5	4	1	2.07	1.95	3	15.5	0.01258	0.0055
15	24	5	4	1	2.07	1.95	3	15.5	0.01258	0.0040
30	24	5	4	1	2.07	1.95	3	15.5	0.01258	0.0029
90	24	5	4	1	2.07	1.95	3	15.5	0.01258	0.0029
180	24	4	4	0	0	0	2	15.6	0.01258	0
240	24	4	4	0	0	0	2	15.6	0.01258	0
480	24	4	4	0	0	0	2	15.6	0.01258	0
1440	24	4	4	0	0	0	2	15.6	0.01258	0

TP2 @ 0.5m

BS Sieve (mm)	Mass retained (g)	Percentage Retained (%)	Percentage Passing (%)
19	18.43	3.69	96.31
9.5	43.31	8.66	87.65
4.75	20.51	4.10	83.55
2.36	36.2	7.24	76.31
1.18	78.5	15.7	60.61
0.6	89.65	17.93	42.68
0.3	52.87	10.57	32.11
0.15	36.17	7.23	24.87
0.075	14.74	2.95	21.92
-0.075T	109.62	21.92	

Elapsed Time, t (min)	Temp (°C)	Hydrometer Reading (Rh)	Composite Correction (CC)	Corrected Reading (Rh1 = Rh-CC)	P% Finer than	P1% Finer than	Rh –Cm	Effective depth from table 5 (mm)	K values from table 4	Particle Diameter, D (mm)
1	26	18	4	13	27.04	19.85	15	13.3	0.013036	0.0151
2	26	17	4	13	27.04	19.85	15	13.5	0.013036	0.0107
4	26	14	4	11	22.89	16.79	13	14.0	0.013036	0.0077
8	25	13	4	9	18.72	13.74	11	14.2	0.013186	0.0056
15	25	11	4	6	12.48	9.16	8	14.5	0.013186	0.0041
30	24	10	4	6	12.48	9.16	8	14.7	0.01336	0.0030
90	24	10	4	5	10.40	7.63	7	14.7	0.01336	0.0017
180	24	9	4	4	8.32	6.11	6	14.8	0.01336	0.0012
240	24	7	4	3	6.24	4.58	5	15.2	0.01336	0.0011
480	24	5	4	1	2.08	1.53	3	15.5	0.01336	0.0008
1440	24	4	4	0	0.00	0.00	2	15.6	0.01336	0.0004

TP2 @ 1m

BS Sieve (mm)	Mass retained (g)	Percentage Retained (%)	Percentage Passing (%)
19	10.34	2.068	97.93
9.5	15.51	3.102	94.83
4.75	15.98	3.196	91.63
2.36	20.11	4.022	87.61
1.18	101.23	20.246	67.37
0.6	126.18	25.236	42.13
0.3	70.23	14.046	28.08
0.15	39.17	7.834	20.25
0.075	16.33	3.266	16.98
-0.075T	84.92	16.98	

Elapsed Time, t (min)	Temp (°C)	Hydrometer Reading (Rh)	Composite Correction (CC)	Corrected Reading (Rh1 = Rh-CC)	P% Finer than	P1% Finer than	Rh –Cm	Effective depth from table 5 (mm)	K values from table 4	Particle Diameter, D (mm)
1	24	9	4	4	8.29	7.26	6	14.8	0.01258	0.0154
2	24	8	4	2	4.14	3.63	4	15.0	0.01258	0.0110
4	24	6	4	2	4.14	3.63	4	15.3	0.01258	0.0078
8	24	6	4	1	2.07	1.81	3	15.3	0.01258	0.0055
15	24	5	4	1	2.07	1.81	3	15.5	0.01258	0.0040
30	24	5	4	1	2.07	1.81	3	15.5	0.01258	0.0029
90	24	4	4	0	0	0	2	15.6	0.01258	0
180	24	4	4	0	0	0	2	15.6	0.01258	0
240	24	4	4	0	0	0	2	15.6	0.01258	0
480	24	4	4	0	0	0	2	15.6	0.01258	0
1440	24	4	4	0	0	0	2	15.6	0.01258	0

4c. Atterberg limits

Liquid Limit

Depth (m)	0.5		0.5	
Position	TP1		TP2	
Experiment	1	2	1	2
Number of blows	17	27	22	30
Tare number	914	122	632	28
Mass of empty tare	12.67	12.77	12.89	12.71
Mass of tare + wet sample	67.62	65.70	66.51	64.85
Mass of tare + dry sample	56.39	54.96	55.33	53.72
Mass of dry soil (g)	43.72	42.19	42.44	41.01
Mass of water (g)	11.23	10.74	11.18	11.13
Moisture content (%)	25.7	25.5	26.3	27.1
Correction factor	0.96	1.01	0.99	1.02
Corrected moisture content (%)	24.7	25.7	26.1	27.7
Average moisture content (%)	25.2		26.9	

Plastic limit

Depth (m)	0.5		0.5	
Position	TP1		TP2	
Tare number	55	21	36	87
Mass of empty tare	12.55	12.8	12.81	12.71
Mass of tare + wet sample	27.96	26.09	25.64	23.33
Mass of tare + dry sample	26.41	24.7	24.27	22.21
Mass of dry soil (g)	13.86	11.9	11.46	9.5
Mass of water (g)	1.55	1.39	1.37	1.12
Moisture content (%)	11.2	11.7	12.0	11.8
Average moisture content (%)	11.4		11.9	

4d. Texas triaxial test

Data set used to determine optimum moisture content

Sample number	1	2	3	4	5
Mass of material	8250	8250	8250	8250	8250
% water added	6	7	8	9	10
Mass of water required	495	578	660	743	825
Mould number	D	C	D	C	D
Mass of specimen + mould	16875	16883	17109	17267	17232
Mass of specimen	8625	8633	8859	9017	8982
Dial reference	195	195	195	195	195
Dial reading	10.5	8.5	10.8	10.5	10.5
Height of specimen	205.5	203.5	205.8	205.5	205.5
Volume per linear	190.3	190	190.3	190	190.3
Volume of specimen	39107	38665	39164	39045	39107
Wet density	2206	2233	2262	2309	2297
Tare + wet sample	4020	4020	4020	4020	4020
Tare + dry sample	4000	4000	4000	4000	4000
Hygroscopic moisture content	0.995	0.995	0.995	0.995	0.995
Mass of water required	536	619	701	784	866
Mass of dry sample	8209	8209	8209	8209	8209
Actual % water added	6.5	7.5	8.5	9.5	10.5
Dry density	2070	2076	2084	2108	2078

Data set used to come up with triaxial specimen

Mass of material	8250	8250	8250	8250	8250
% water added	9	9	9	9	9
Mass of water required	743	743	743	743	743
Mould number	D	C	D	C	D
Mass of specimen + mould	17265	17309	17279	17272	17270
Mass of specimen	9015	9059	9029	9022	9020
Dial reference	195	195	195	195	195
Dial reading	10.2	11.7	10.6	11.1	10.3
Height of specimen	205.2	206.7	205.6	206.1	205.3
Volume per linear	190.3	190	190.3	190	190.3
Volume of specimen	39050	39273	39126	39159	39069
Wet density	2309	2307	2308	2304	2309
Tare + dry sample	4020	4020	4020	4020	4020
Tare + oven-dried dry sample	4000	4000	4000	4000	4000
Hygroscopic moisture content	0.995	0.995	0.995	0.995	0.995
Mass of water required	784	784	784	784	784
Mass of dry sample	8209	8209	8209	8209	8209
Actual % water added	9.5	9.5	9.5	9.5	9.5
Dry density	2107	2106	2107	2103	2108

Compression stage results

Deformation	Height	Load	Uncorrected stress	1-strain	Corrected stress		Lateral pressure
4.1	205.3	0.9	50.93	0.98	50	45	0
3.0	206.7	0.7	39.61	0.99	39		0
8.9	206.7	3.5	198.06	0.97	190		20
7.3	205.2	5.4	305.58	0.96	295		40
8.5	205.6	4.2	450.37	0.96	440		70

Data set used to draw Mohr circles

Axial pressure	**0**		**20**		**40**		**70**	
Angle (θ)	$\sigma_n = \sigma_{avg} + R\cos 2\theta$	$\tau_n = R\sin 2\theta$	$\sigma_n = \sigma_{avg} + R\cos 2\theta$	$\tau_n = R\sin 2\theta$	$\sigma_n = \sigma_{avg} + R\cos 2\theta$	$\tau_n = R\sin 2\theta$	$\sigma_n = \sigma_{avg} + R\cos 2\theta$	$\tau_n = R\sin 2\theta$
0	45	0	190	0	295	0	440	0
1	45	0	190	1	295	2	440	3
2	45	1	190	3	295	4	440	6
3	45	1	190	4	295	7	440	10
4	45	2	190	6	295	9	440	13
5	45	2	190	7	295	11	439	16
6	45	2	190	9	294	13	439	19
7	45	3	189	10	294	16	439	23
8	45	3	189	12	294	18	438	26
9	45	4	189	13	293	20	438	29
10	45	4	189	15	293	22	437	32
11	45	4	188	16	293	24	437	35
12	45	5	188	18	292	27	436	38
13	44	5	188	19	292	29	435	42
14	44	5	187	21	291	31	435	45
15	44	6	187	22	291	33	434	48
16	44	6	187	23	290	35	433	51
17	44	7	186	25	289	37	432	54
18	44	7	186	26	289	39	431	57
19	44	7	185	28	288	42	430	60
20	44	8	185	29	287	44	429	63
21	44	8	184	30	287	46	428	66
22	43	8	184	32	286	48	427	69
23	43	9	183	33	285	50	425	72
24	43	9	183	35	284	52	424	75
25	43	10	182	36	283	54	423	78
26	43	10	181	37	282	56	421	81
27	43	10	181	39	281	58	420	84

28	42	11	180	40	280	60	418	87
29	42	11	179	41	279	62	417	90
30	42	11	179	42	278	64	415	92
31	42	12	178	44	277	66	414	95
32	42	12	177	45	276	68	412	98
33	41	12	176	46	274	69	410	101
34	41	13	175	48	273	71	408	103
35	41	13	175	49	272	73	407	106
36	41	13	174	50	271	75	405	109
37	40	14	173	51	269	77	403	111
38	40	14	172	52	268	78	401	114
39	40	14	171	53	267	80	399	116
40	40	14	170	55	265	82	397	119
41	39	15	169	56	264	84	395	121
42	39	15	168	57	262	85	392	124
43	39	15	167	58	261	87	390	126
44	39	16	166	59	259	89	388	128
45	38	16	165	60	258	90	386	131
46	38	16	164	61	256	92	384	133
47	38	16	163	62	254	93	381	135
48	38	17	162	63	253	95	379	137
49	37	17	161	64	251	96	376	140
50	37	17	160	65	249	98	374	142
51	37	17	159	66	248	99	371	144
52	36	18	157	67	246	100	369	146
53	36	18	156	68	244	102	366	148
54	36	18	155	69	242	103	364	150
55	35	18	154	70	241	104	361	152
56	35	19	153	70	239	106	358	153
57	35	19	151	71	237	107	356	155
58	34	19	150	72	235	108	353	157
59	34	19	149	73	233	109	350	159
60	34	19	148	74	231	110	348	160
61	33	20	146	74	229	112	345	162
62	33	20	145	75	227	113	342	163
63	33	20	144	76	225	114	339	165
64	32	20	142	76	223	115	336	166
65	32	20	141	77	221	116	333	168
66	32	21	140	78	219	116	330	169
67	31	21	138	78	217	117	327	170
68	31	21	137	79	215	118	324	172
69	31	21	135	79	213	119	321	173

70	30	21	134	80	211	120	318	174
71	30	21	133	80	209	121	315	175
72	29	21	131	81	207	121	312	176
73	29	22	130	81	205	122	309	177
74	29	22	128	82	203	123	306	178
75	28	22	127	82	201	123	303	179
76	28	22	126	82	198	124	300	179
77	28	22	124	83	196	124	297	180
78	27	22	123	83	194	125	294	181
79	27	22	121	83	192	125	290	182
80	26	22	120	84	190	126	287	182
81	26	22	118	84	187	126	284	183
82	26	22	117	84	185	126	281	183
83	25	22	115	84	183	127	278	184
84	25	22	114	85	181	127	274	184
85	24	22	112	85	179	127	271	184
86	24	22	111	85	176	127	268	185
87	24	22	109	85	174	127	265	185
88	23	22	108	85	172	127	262	185
89	23	22	107	85	170	127	258	185
90	23	22	105	85	168	127	255	185
91	22	22	104	85	165	127	252	185
92	22	22	102	85	163	127	249	185
93	21	22	101	85	161	127	245	185
94	21	22	99	85	159	127	242	185
95	21	22	98	85	156	127	239	184
96	20	22	96	85	154	127	236	184
97	20	22	95	84	152	127	233	184
98	19	22	93	84	150	126	229	183
99	19	22	92	84	148	126	226	183
100	19	22	90	84	145	126	223	182
101	18	22	89	83	143	125	220	182
102	18	22	87	83	141	125	217	181
103	17	22	86	83	139	124	213	180
104	17	22	84	82	137	124	210	180
105	17	22	83	82	135	123	207	179
106	16	22	82	82	132	123	204	178
107	16	22	80	81	130	122	201	177
108	16	21	79	81	128	121	198	176
109	15	21	77	80	126	121	195	175
110	15	21	76	80	124	120	192	174
111	14	21	75	79	122	119	189	173

112	14	21	73	79	120	118	186	172
113	14	21	72	78	118	117	183	170
114	13	21	70	78	116	116	180	169
115	13	20	69	77	114	116	177	168
116	13	20	68	76	112	115	174	166
117	12	20	66	76	110	114	171	165
118	12	20	65	75	108	113	168	163
119	12	20	64	74	106	112	165	162
120	11	19	63	74	104	110	163	160
121	11	19	61	73	102	109	160	159
122	11	19	60	72	100	108	157	157
123	10	19	59	71	98	107	154	155
124	10	19	57	70	96	106	152	153
125	10	18	56	70	94	104	149	152
126	9	18	55	69	93	103	146	150
127	9	18	54	68	91	102	144	148
128	9	18	53	67	89	101	141	146
129	8	17	52	66	87	99	139	144
130	8	17	50	65	86	98	136	142
131	8	17	49	64	84	96	134	140
132	7	17	48	63	82	95	131	138
133	7	16	47	62	81	93	129	135
134	7	16	46	61	79	92	127	133
135	7	16	45	60	77	90	124	131
136	6	16	44	59	76	89	122	129
137	6	15	43	58	74	87	120	126
138	6	15	42	57	73	85	118	124
139	6	15	41	56	71	84	115	121
140	5	14	40	55	70	82	113	119
141	5	14	39	54	68	80	111	116
142	5	14	38	52	67	79	109	114
143	5	14	37	51	66	77	107	111
144	4	13	36	50	64	75	105	109
145	4	13	35	49	63	73	104	106
146	4	13	35	48	62	71	102	104
147	4	12	34	46	61	69	100	101
148	3	12	33	45	59	68	98	98
149	3	12	32	44	58	66	96	95
150	3	11	31	43	57	64	95	93
151	3	11	31	41	56	62	93	90
152	3	11	30	40	55	60	92	87
153	2	10	29	39	54	58	90	84

154	2	10	29	37	53	56	89	81
155	2	10	28	36	52	54	87	78
156	2	9	27	35	51	52	86	75
157	2	9	27	33	50	50	85	72
158	2	8	26	32	49	48	84	69
159	1	8	26	31	48	46	82	66
160	1	8	25	29	48	44	81	63
161	1	7	25	28	47	42	80	60
162	1	7	24	26	46	39	79	57
163	1	7	24	25	46	37	78	54
164	1	6	23	23	45	35	77	51
165	1	6	23	22	44	33	76	48
166	1	5	23	21	44	31	76	45
167	1	5	22	19	43	29	75	42
168	0	5	22	18	43	27	74	39
169	0	4	22	16	42	24	73	35
170	0	4	21	15	42	22	73	32
171	0	4	21	13	42	20	72	29
172	0	3	21	12	41	18	72	26
173	0	3	21	10	41	16	71	23
174	0	2	20	9	41	13	71	19
175	0	2	20	7	40	11	71	16
176	0	2	20	6	40	9	70	13
177	0	1	20	4	40	7	70	10
178	0	1	20	3	40	5	70	7
179	0	0	20	2	40	2	70	3
180	0	0	20	0	40	0	70	0

4e. Compaction test

Calculations

Volume of mould = 2250ml = 0.00225m^3

Mass of wet sample = [(Mass of mould + wet sample) – mass of mould]

Wet density, $\rho = \frac{mass\ of\ wet\ sample}{volume\ of\ mould}\ (kg/m^3)$

Mass of water = [(mass of tare + wet sample) - (mass of tare + dry soil)]

Mass of dry soil= [Mass of tare + dry soil) – mass of tare]

Moisture content, $w = \frac{mass\ of\ water}{mass\ of\ \ dry\ soil} \times 100\ (\%)$

Dry density, $\rho_d = \frac{\rho}{1+w}\ (kg/m^3)$

TP1

Experiment Number	1	2	3	4
Mould number	3	T	1	5
Mass of empty mould (m_1, g)	4490	4475	4100	3355
Mass of empty mould + sample (m_2, g)	9800	9155	8486	8029
Mass of wet sample (g)	5310	4680	4386	4674
Mass of wet sample (kg)	5.310	4.680	4.386	4.674
Volume of water added (ml)	600	500	400	700
Wet density/ ρ (kg/m^3)	2360	2080	1949	2077
Tare number	5	AM9	AM7	S3
Tare mass (g)	280	279	280	285
Tare mass + wet sample (g)	680	679	680	685
Tare mass + dry sample (g)	647	652	659	649
Mass of dry sample (g)	367	373	379	364
Mass of water (g)	33	27	21	36
Moisture Content (%)	9.0	7.2	5.5	9.9
Dry density, ρ_d (kg/m^3)	2165	1940	1847	1890

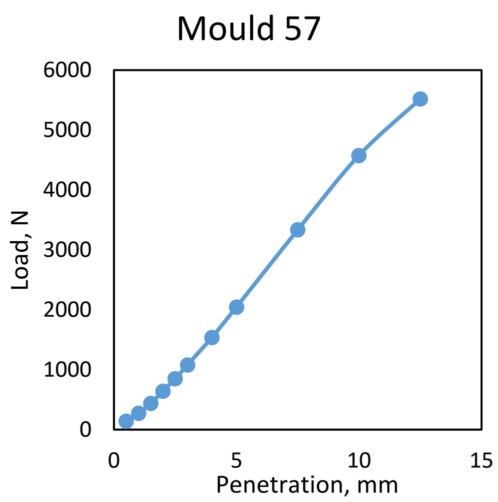
TP2

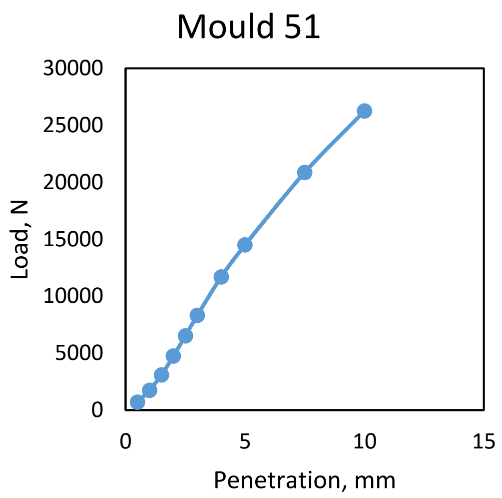
Experiment Number	1	2	3	4
Mould number	3	T	1	5
Mass of empty mould (m_1, g)	4490	4475	4100	3355
Mass of empty mould + sample (m_2, g)	9749	9155	9019	8009
Mass of wet sample (g)	5259	4680	4919	4654
Mass of wet sample (kg)	5.259	4.680	4.919	4.654
Volume of water added (ml)	600	500	700	800
Wet density/ ρ (kg/m^3)	2337	2080	2186	2068
Tare number	5	AM9	AM7	S3
Tare mass (g)	280	279	280	285
Tare mass + wet sample (g)	680	679	680	685
Tare mass + dry sample (g)	646	650	644	647
Mass of dry sample (g)	366	371	364	362
Mass of water (g)	34	29	36	38
Moisture Content (%)	9.3	7.8	9.9	10.5
Dry density, ρ_d (kg/m^3)	2139	1929	1989	1872

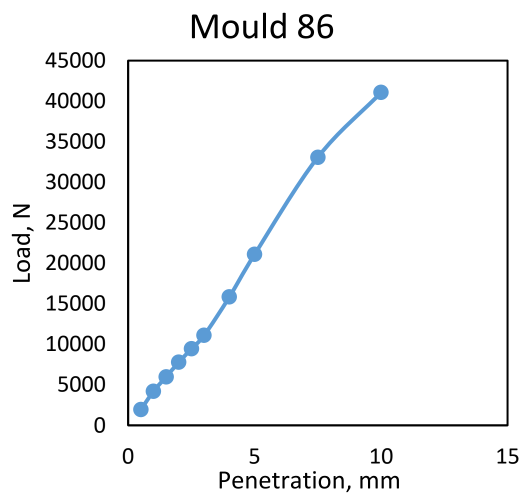
4f. Strength development tests with time.

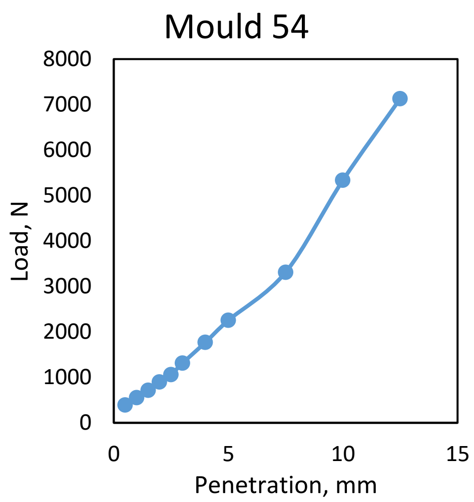
7 DAYS									
Penetration (mm)	**Mould 57**			**Mould 51**			**Mould 86**		
	Untreated, soaked test			**Stabilised, soaked test**			**Stabilised, dry test**		
	Dial gauge (mm)	**Load (N)**	**% CBR**	**Dial gauge (mm)**	**Load (N)**	**% CBR**	**Dial gauge (mm)**	**Load (N)**	**% CBR**
0.5	6	138		30	690		84	1932	
1	12	276		76	1748		182	4186	
1.5	19	437		134	3082		260	5980	
2	28	644		206	4738		338	7774	
2.5	37	851	**18**	183	4209	**66**	410	9430	**125**
	102	2346		378	8694		720	16560	
3	47	1081		361	8303		482	11086	
4	67	1541		508	11684		688	15824	
5	89	2047	**20**	630	14490	**87**	917	21091	**165**
	177	4071		756	17388		1438	33074	
7.5	145	3335		907	20861		1438	33074	
10	199	4577		1141	26243		1785	41055	

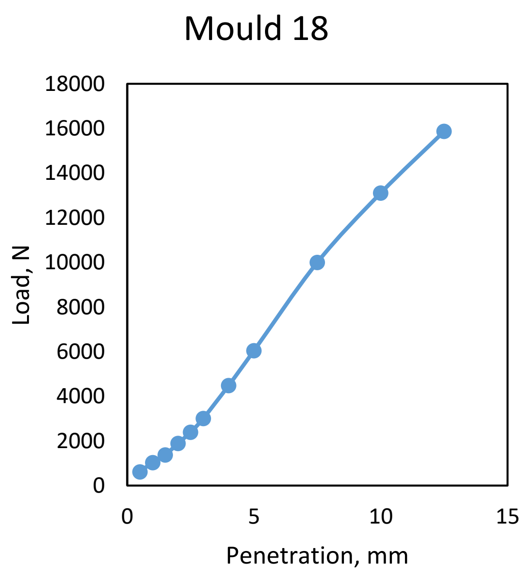
28 DAYS									
Penetration (mm)	**Mould 54**			**Mould 18**			**Mould 26**		
	Untreated, soaked test			**Stabilised, soaked test**			**Stabilised, dry test**		
	Dial gauge	**Load (N)**	**% CBR**	**Dial gauge (mm)**	**Load (N)**	**% CBR**	**Dial gauge (mm)**	**Load (N)**	**% CBR**
0.5	17	391		27	621		130	2990	
1	24	552		45	1035		287	6601	
1.5	31	713		60	1380		444	10212	
2	39	897		82	1886		598	13754	
2.5	46	1058	**18**	104	2392	**80**	745	17135	**129**
	105	3220		460	10580		-	-	
3	57	1311		131	3013		935	21505	
4	77	1771		195	4485		1322	30406	
5	98	2254	**22**	263	6049	**99**	1706	39238	**196**
	188	5865		820	18860		-	-	
7.5	144	3312		435	10005		2664	61272	
10	232	5336		570	13110		3289	75647	
12.5	310	7130		690	15870		3928	90344	

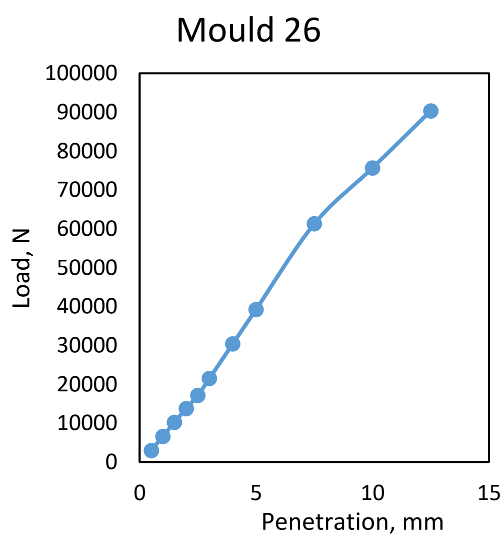

Mould 57
Load, N
6000
5000
4000
3000
2000
1000
0
0
5
10
15
Penetration, mm


Mould 51
Load, N
30000
25000
20000
15000
10000
5000
0
0
5
10
15
Penetration, mm


Mould 86
Load, N
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
5
10
15
Penetration, mm


Mould 54
Load, N
8000
7000
6000
5000
4000
3000
2000
1000
0
0
5
10
15
Penetration, mm


Mould 18
Load, N
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
5
10
15
Penetration, mm


Mould 26
Load, N
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
5
10
15
Penetration, mm

4g. Pictures of tests performed.

Screening the sample (separating fine material from coarse) in preparation for backmixing and testing

Wet sieved sample after washing ready to be oven dried.

Dry sieving done in the laboratory with a series of BS sieves

Particle size distribution of samples after dry sieving

(At 0.5m & 1m depth)

Preparation of sample for compaction.

Compaction of samples to low compactive effort (LCE)

Control and treated samples compacted and left to cure for 7 and 28days.

The CBR machine used for strength determination of both the dry and soaked compacted samples, treated and untreated

Appendix 5: Pavement design

KEY TO STRUCTURAL CATALOGUE

Traffic classes (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

Subgrade strength classes (CBR%)

S1 = 2
S2 = 3 , 4
S3 = 5 - 7
S4 = 8 - 14
S5 = 15 - 29
S6 = 30+

Material Definitions

Double surface dressing

Flexible bituminous surface

Bituminous surface
(Usually a wearing course, WC, and a basecourse, BC)

Bituminous roadbase, RB

Granular roadbase, GB1 - GB3

Granular sub-base, GS

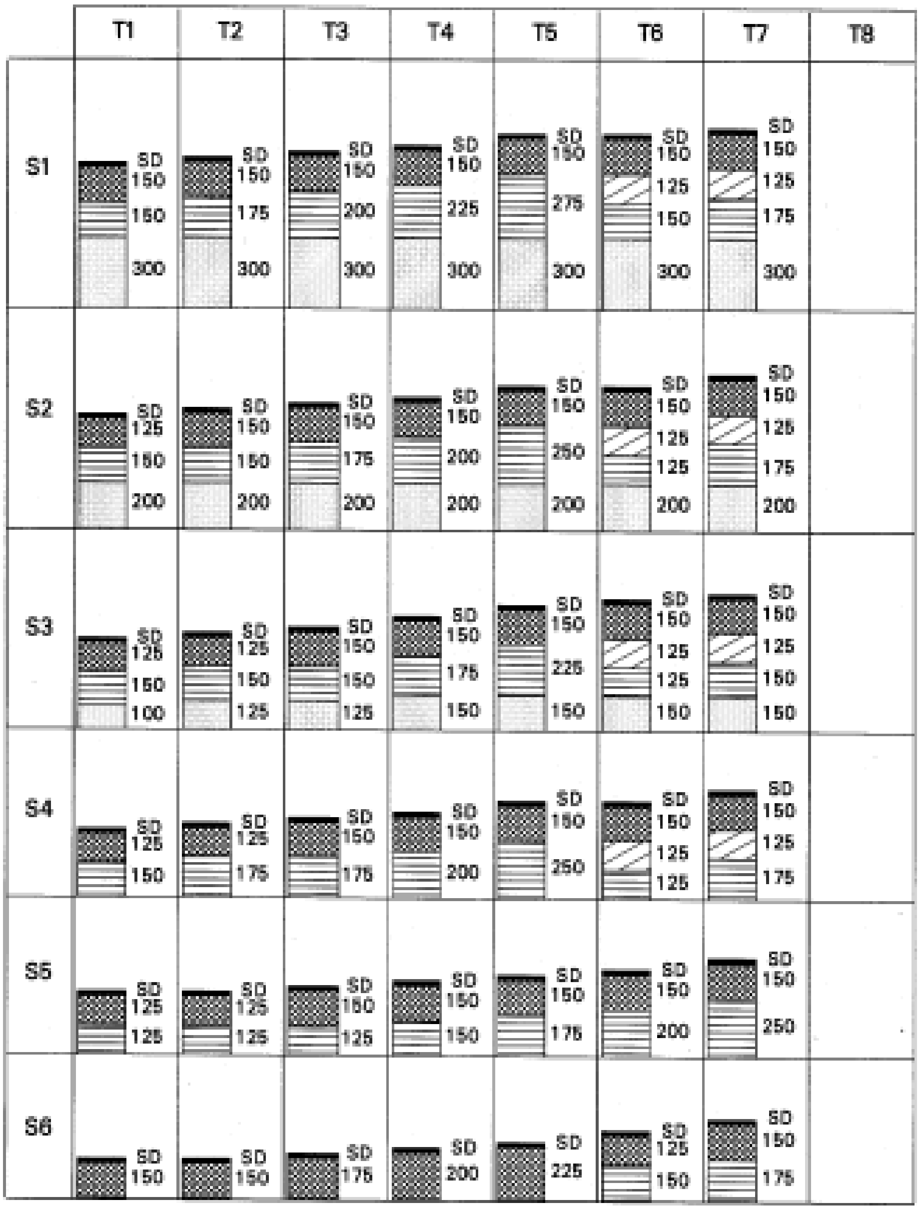
Granular capping layer or selected subgrade fill, GC

Cement or lime-stabilised roadbase 1, CB1

Cement or lime-stabilised roadbase 2, CB2

Cement or lime-stabilised sub-base, CS

CHART 2 COMPOSITE ROAD BASE (UNBOUND & CEMENTED) / SURFACE DRESSING



Note: Sub-base to fill substitution not permitted.

Appendix 6: Material quantities

Road length = 2 000m	
Stabilisation width = 8.2m **Stabilised layer thickness =** 0.12m	**Crushed stone width** = 7.6m **Crushed stone layer thickness =** 0.15m
Stabilisation volume = L × W × T = 2000 × 8.2 × 0.12 **= 1 968m³**	**Crushed stone volume** = L × W × T = 2000 × 7.6 × 0.15 = **2 280m³**
Stabiliser quantities	
EarthZyme solution	**Cement**
Using the ratio of 1:33, for the 2km pavement construction: $\mathbf{\frac{1\,968}{33} = 60\ \textit{litres of EZ required.}}$	Using 2% cement proportion, for the 2km pavement construction: $m = \rho \times V \times cement\ \%$ $m = 2190 \times 1\,968 \times \frac{2}{100}$ $= 86\,199\ kg$ $= \mathbf{86\ \textit{tonnes of cement required.}}$

Appendix 7: Bill of quantities

A. BoQ for design with EarthZyme solution stabilisation

BILL OF QUANTITIES Name of work: Construction of a 2km flexible pavement for Chitungwiza road rehabilitation program.					
Item No.	**Description**	**Quantity**	**Rate**	**Unit**	**Amount (US$)**
1000	**GENERAL**				
1400	**HOUSING, OFFICES AND LABOUR FOR ENGINEER'S PERSONNEL ON SITE**				
14.01(a)	Office furniture and detergents	1.00	40,000.00	PC sum	40 000.00
14.01(b)	Office stationery, printers and laptops	1.00	20,000.00	PC sum	20 000.00
1500	**ACCOMMODATION OF TRAFFIC**				
15.01(a)	Traffic safety officer	rate only	744.58	month	
15.03	Temporary traffic control facilities	1.00	7,800.00	Lump sum	7 800.00
1700	**CLEARING AND GRUBBING**				
17.01	Clearing bushes and trimming trees	2.00	2,207.48	ha	4 414.96
17.04	Clearing existing open side drains, both sides	4.00	2,730.74	km	10 922.96
	Total carried forward to summary				**83 137.92**
2000	**DRAINAGE**				
2100	**DRAINS**				
21.02	Shaping existing drains, both sides	4.00	4,452.39	km	17 809.56
2300	**CONCRETE KERBING AND CHANNELLING**				
23.01(a)	Remove, stack and reinstall undamaged kerbs with black and white kerb-face painting	450.00	56.48	m	25 416.00
23.01(b)	Supply and lay non-mountable kerbs (similar to existing kerbs)	300.00	54.92	m	16 476.00
	Total carried forward to summary				**59 701.56**
3000	**EARTHWORKS AND PAVEMENT LAYERS OF GRAVEL AND CRUSHED STONE**				

3400	**PAVEMENT LAYERS OF GRAVEL MATERIAL**				
34.03(d. ii)	Construction of 120mm subbase from existing material (cold in-place recycling), compact to 95% Mod AASHTO density	1,680.00	5.80	m^3	9 744.00
3500	**STABILISATION**				
	Supply EarthZyme solution road stabiliser to stabilise the subbase.	60	250.00	litre	15 000.00
3600	**CRUSHED STONE BASE**				
36.01	Supply crushed stone for Base 1 material obtained from commercial sources, and compacted to 100% Mod AASHTO density	2,964.00	17.00	m^3	50 388.00
3800	**BREAKING EXISTING PAVEMENT**				
	Cold in-place recycling of existing pavement				
38.02(a)	Rip and mill to a depth of 120mm of existing pavement, blading to windrow	1,680.00	20.19	m^3	33 919.20
	Total carried forward to summary				**109 051.20**
4000	**SEALS**				
4100	**PRIME COAT**				
41.01	E-prime coat applied at 0.80 l/m^2	Rate only	2.98	litre	
41.01(c)	MC-30 cut-back bitumen 0.80 l/m^2	14,000.00	2.98	litre	41 720.00
41.02	Aggregate for blinding	Rate only	3.75	m^2	
4500	**DOUBLE SEAL**				
45.01	Supply all materials for and apply double seal spray and chip surfacing: i. Straight run 70/100 penetration grade bitumen at 1.2 l/m^2 tack coat and 0.90 l/m^2 seal coat.	rate only	3.52	litre	
	ii. 19mm aggregate for tack coat at 0.013 m^3/m^2 aggregate application rate iii. 9.5mm aggregate for seal coat at 0.009 m^3/m^2 aggregate application rate. (Seal coat aggregate should be precoated.)	14,000.00	11.72	m^2	164 080.00

45.03	Aggregate variations				
45.03(a)	19mm aggregate	rate only	152.67	m^3	
45.03(b)	13.2mm aggregate	rate only	152.67	m^3	
4000	**Total carried forward to summary**				**205 800.00**
5000	**ANCILLARY ROADWORKS**				
5400	**ROAD SIGNS**				
54.01(a)	Supply road sign boards with coloured background	15	340.00	m^2	5 100.00
54.03(b)	Supply and install road-sign supports made of timber- 100mm diameter and clamps	25	250.00	No.	6 250.00
54.04	Excavation and backfilling for road sign supports	25	250.00	m^3	6 250.00
5500	**ROAD MARKINGS**				
55.02(a)	Spray painting 100mm-wide (min) retro-reflective white lines, both broken and unbroken	2.00	2,215.32	km	4 430.64
55.02(b)	Spray painting 100mm-wide (min) retro-reflective yellow lines, both broken and unbroken	4.00	2,374.99	km	9 499.96
55.02(d)	White lettering and symbols (Retro-reflective)	rate only	75.00	m^2	
55.05	Installation of road studs (Colours specified by Engineer)	150	7.80	No.	1 170.00
5000	**Total carried forward to summary**				**32 700.60**

B. BoQ for design with cement stabilisation

BILL OF QUANTITIES Name of work: Construction of a 2km flexible pavement for Chitungwiza road rehabilitation program.					
Item No.	**Description**	**Quantity**	**Rate**	**Unit**	**Amount (US$)**
1000	**GENERAL**				
1400	**HOUSING, OFFICES AND LABOUR FOR ENGINEER'S PERSONNEL ON SITE**				
14.01(a)	Office furniture and detergents	1.00	40,000.00	PC sum	40 000.00
14.01(b)	Office stationery, printers and laptops	1.00	20,000.00	PC sum	20 000.00
1500	**ACCOMMODATION OF TRAFFIC**				

15.01(a)	Traffic safety officer	rate only	744.58	month	
15.03	Temporary traffic control facilities	1.00	7,800.00	Lump sum	7 800.00
1600	**OVERHAUL OF GRAVEL**				
16.01(i)	Hauling gravel from approved borrow pit (free haul up to 1km)	Rate only	11.31	m^3	
16.01(ii)	Overhaul gravel from borrow pits in excess of free haul distance	2,000.00	1.13	m^3-km	2 260.00
1700	**CLEARING AND GRUBBING**				
17.01	Clearing bushes and trimming trees	2.00	2,207.48	ha	4 414.96
17.04	Clearing existing open side drains, both sides	4.00	2,730.74	km	10 922.96
	Total carried forward to summary				**85 397.92**
2000	**DRAINAGE**				
2100	**DRAINS**				
21.02	Shaping existing drains, both sides	4.00	4,452.39	km	17 809.56
2300	**CONCRETE KERBING AND CHANNELLING**				
23.01(a)	Remove, stack and reinstall undamaged kerbs with black and white kerb-face painting	450.00	56.48	m	25 416.00
23.01(b)	Supply and lay non-mountable kerbs (similar to existing kerbs)	300.00	54.92	m	16 476.00
	Total carried forward to summary				**59 701.56**
3000	**EARTHWORKS AND PAVEMENT LAYERS OF GRAVEL AND CRUSHED STONE**				
3100	**BORROW MATERIALS**				
31.01	Clearing and grubbing for opening gravel pit	1	2,207.48	ha	2 207.48
31.02	Stockpiling of material	1,700.00	6.94	m^3	11 798.00
31.03	Rehabilitation of gravel pits	1	3.469.24	ha	3 469.24
3400	**PAVEMENT LAYERS OF GRAVEL MATERIAL**				
34.01(c. i)	Construction of 120mm subbase with gravel from borrow pit, compact to 95% Mod AASHTO density	1,680.00	7.80	m^3	13 104.00
3500	**STABILISATION**				

	Supply ordinary Portland cement road stabiliser to stabilise the subbase.	86	457.60	tonne	39 353.60
3600	**CRUSHED STONE BASE**				
36.01	Supply crushed stone for Base 1 material obtained from commercial sources, and compacted to 100% Mod AASHTO density	2,964.00	17.00	m^3	50 388.00
3800	**BREAKING EXISTING PAVEMENT**				
	Cold in-place recycling of existing pavement				
38.02(a)	Rip and mill to a depth of 120mm of existing pavement, blading to windrow	1,680.00	20.19	m^3	33 919.20
	Total carried forward to summary				**154 239.52**
4000	**SEALS**				
4100	**PRIME COAT**				
41.01	E-prime coat applied at 0.80 l/m^2	Rate only	2.98	litre	
41.01(c)	MC-30 cut-back bitumen 0.80 l/m^2	14,000.00	2.98	litre	41 720.00
41.02	Aggregate for blinding	Rate only	3.75	m^2	
4500	**DOUBLE SEAL**				
45.01	Supply all materials for and apply double seal spray and chip surfacing: i. Straight run 70/100 penetration grade bitumen at 1.2 l/ m^2 tack coat and 0.90 l/ m^2 seal coat.	rate only	3.52	litre	
	ii. 19mm aggregate for tack coat at 0.013 m^3/ m^2 aggregate application rate iii. 9.5mm aggregate for seal coat at 0.009 m^3/ m^2 aggregate application rate. (Seal coat aggregate should be precoated.)	14,000.00	11.72	m^2	164 080.00
45.03	Aggregate variations				
45.03(a)	19mm aggregate	rate only	152.67	m^3	
45.03(b)	13.2mm aggregate	rate only	152.67	m^3	
4000	**Total carried forward to summary**				**205 800.00**

5000	**ANCILLARY ROADWORKS**				
5400	**ROAD SIGNS**				
54.01(a)	Supply road sign boards with coloured background	15	340.00	m^2	5 100.00
54.03(b)	Supply and install road-sign supports made of timber- 100mm diameter and clamps	25	250.00	No.	6 250.00
54.04	Excavation and backfilling for road sign supports	25	250.00	m^3	6 250.00
5500	**ROAD MARKINGS**				
55.02(a)	Spray painting 100mm-wide (min) retro-reflective white lines, both broken and unbroken	2.00	2,215.32	km	4 430.64
55.02(b)	Spray painting 100mm-wide (min) retro-reflective yellow lines, both broken and unbroken	4.00	2,374.99	km	9 499.96
55.02(d)	White lettering and symbols (Retro-reflective)	rate only	75.00	m^2	
55.05	Installation of road studs (Colours specified by Engineer)	150	7.80	No.	1 170.00
5000	**Total carried forward to summary**				**32 700.60**

Appendix 8: Road elevations data

Chainage	Base 2	Base 1	Finished Road Level	Ground Level
			CENTER ELEVATION	
0+000	1442.251	1442.401	1442.441	1442.021
0+040	1442.528	1442.678	1442.718	1442.298
0+080	1443.019	1443.169	1443.209	1442.789
0+120	1443.687	1443.837	1443.877	1443.457
0+160	1444.569	1444.719	1444.759	1444.339
0+200	1445.589	1445.739	1445.779	1445.359
0+240	1446.639	1446.789	1446.829	1446.409
0+280	1447.684	1447.834	1447.874	1447.454
0+320	1448.670	1448.820	1448.860	1448.44
0+360	1449.597	1449.747	1449.787	1449.367
0+400	1450.418	1450.568	1450.608	1450.188
0+440	1451.198	1451.348	1451.388	1450.968
0+480	1451.936	1452.086	1452.126	1451.706
0+520	1452.578	1452.728	1452.768	1452.348
0+560	1453.160	1453.310	1453.350	1452.93
0+600	1453.690	1453.840	1453.880	1453.46
0+640	1454.128	1454.278	1454.318	1453.898
0+680	1454.506	1454.656	1454.696	1454.276

0+720	1454.853	1455.003	1455.043	1454.623
0+760	1455.092	1455.242	1455.282	1454.862
0+800	1455.281	1455.431	1455.471	1455.051
0+840	1455.421	1455.571	1455.611	1455.191
0+880	1455.568	1455.718	1455.758	1455.338
0+920	1455.691	1455.841	1455.881	1455.461
0+960	1455.830	1455.980	1456.020	1455.600
1+000	1455.961	1456.111	1456.151	1455.731
1+040	1456.083	1456.233	1456.273	1455.853
1+080	1456.245	1456.395	1456.435	1456.015
1+120	1456.368	1456.518	1456.558	1456.138
1+160	1456.533	1456.683	1456.723	1456.303
1+200	1456.701	1456.851	1456.891	1456.471
1+240	1457.000	1457.150	1457.190	1456.770
1+280	1457.417	1457.567	1457.607	1457.187
1+320	1457.920	1458.070	1458.110	1457.690
1+360	1458.570	1458.720	1458.760	1458.340
1+400	1459.139	1459.289	1459.329	1458.909
1+440	1459.664	1459.814	1459.854	1459.434
1+480	1460.074	1460.224	1460.264	1459.844
1+520	1460.389	1460.539	1460.579	1460.159
1+560	1460.582	1460.732	1460.772	1460.352
1+600	1460.669	1460.819	1460.859	1460.439
1+640	1460.693	1460.843	1460.883	1460.463
1+680	1460.631	1460.781	1460.821	1460.401
1+720	1460.599	1460.749	1460.789	1460.369
1+760	1460.595	1460.745	1460.785	1460.365
1+800	1460.693	1460.843	1460.883	1460.463
1+840	1460.816	1460.966	1461.006	1460.586
1+880	1461.031	1461.181	1461.221	1460.801
1+920	1461.300	1461.45	1461.49	1461.070
1+960	1461.551	1461.701	1461.741	1461.321
2+000	1461.825	1461.975	1462.015	1461.595