Stabilisation of a Road Pavement Using Polymeric Stabilisers: Case Study of Christian Road, Shamva District, Zimbabwe

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Abstract. The objective of the research is to design a polymer stabilised road pavement that is capable of preserving the dry strength of the pavement at lower cost of construction, to assess the properties of the polymer the bearing capacity of a polymer stabilised soil and to conduct the road condition survey. The geotechnical site investigations were conducted at the site and these included Dynamic Cone Penetration (DCP) Test and visual soil classification. The laboratory tests on the soil samples included soil classification tests (particle size analysis and plasticity tests), compaction test and California bearing ratio (CBR) test. The design of the road was carried out. The stabiliser SoilTech Mk III polymer was added to the soil at different percentages and the maximum dry densities, CBR and optimum moisture content measured. From the graphs, stabilised soil has a very high maximum dry density of 2365 kg/m³ at an optimum moisture content of 7.2% as compared to the unstabilised sample which has a maximum dry density which ranges from 2116 kg/m³ to 2120 kg/m³ determined above. This shows that SoilTechMkIII increases the maximum dry density of the soil. The optimum of moisture content of the stabilized sample increased by 0.2% from the optimum moisture content which was determined in the higher compactive effort (HCE) test of the unstabilised sample. It is recommended to stabilize the soil in order to increase its bearing capacity. It is also noted that the significance of mixing material thoroughly helps in coming out with more accurate results.

Keywords: Stabiliser, Bearing Capacity, Maximum Dry Density, Geotechnical Investigation, Optimum Moisture Content

1 Introduction

According to Asphalt Emulsion Manufacturers Association (AEMA) (2013), the biggest problem faced by road engineers is the high cost of constructing and maintaining the road system. Moreover, financial restraints and increased traffic volumes and weights are making it difficult for local councils to satisfy community expectations (White and Middleton, 2010). Road engineers are trying to construct a problem-free road pavement that will last for the duration of its intended design life for the most economic price. Construction of roads over soft sub base is one of the most common problems in highway construction in many parts of the world as well as in our country, Zimbabwe. However, this problem of soft subgrades can be overcome by stabilisation of the sub base.

The Ministry of Transport and Infrastructural Development, Zimbabwe intends to upgrade some of the unsealed roads to all weather roads in order to reduce the maintenance costs on which the government is spending year after year. The government proposed to improve these roads by means of soil stabilisation, to achieve this goal. ECOroads, a stabilising agent supplied by Palo Holdings, was selected for trials on the roads in Zimbabwe.
The main objective of soil stabilisation is to improve the performance of soil material by increasing its stiffness, strength and durability (DFID, 2010). The most appropriate method for stabilisation is that which produces a soil material with desired properties at the very minimum cost and the stabilised material should have better qualities than those of natural soil. Stabilisation also reduces the cost price of hauling materials from further away since little or no additional gravel from quarries is transported to the site (DFID, 2000).

There are substantial disadvantages from the currently used stabilisers in Zimbabwe. For example, disadvantages of using cement as a stabiliser involve long transport distances from large scale production facilities of cement to the site of construction over roads susceptible to damage from heavy vehicle loading (Global Transport Knowledge Partnership) (gTKP, 2008). The usual approach in stabilising soft sub base is to remove the soft soil and replace it with a stronger material of crushed rock and this leads to high cost of construction. However, polymer stabilisation uses the available in situ material. Polymer stabilisation provides a way of prolonging pavement life at a lower life cycle cost. The cost savings associated with polymer stabilisation can take many forms including reduced construction costs and reduced maintenance costs throughout the life of the pavement or an extension of the normal pavement life (Wilmot, 2006).

Since 2011, the Zimbabwe Ministry of Transport and Infrastructural Development has been doing some trials on polymer stabilisation using the EcoRoads polymer in Shamva, Mashonaland East. Polymer stabilisation has been employed in countries like South Africa in which in 1996 (Sodwana Bay, KwaZulu Natal) it was observed that four months after polymer stabilisation, there was a strength increase of approximately 300% over the untreated soil. In Mariannridge, KwaZulu Natal, South Africa, a parking lot was polymer stabilised in 1996. After 18 months of use, the parking lot had a surface which was free of distortions despite its use by traffic and subjected to more than 1 500 mm of rainfall.

Jones (1997) cited in (Jones and Emery, 2003) stated that the Council for Scientific and Industrial Research, CSIR, in Gauteng, South Africa, performed a series of tests in 1997 using polymeric stabilisers on 12 different gravel roads. It was observed that four roads that had hard, compacted surfaces at the time of spraying the copolymer emulsion (six months before), were in outstanding conditions regardless of having been subjected to over 100 mm of rain and high traffic. Besides maintaining a satisfactory riding quality and minimising gravel loss during dry conditions, the polymer stabilisation was also observed to minimise slipperiness during wet conditions (Jones, 1997 cited in (Jones and Emery, 2003)). Sections of those roads on which the grader had deposited thick layers of more than 10 mm of loose material, before spraying with the polymer, showed a considerably reduced binding performance.

In 1997, different sections of a road were constructed using polymer stabilisers in Mozambique. Twelve months later, all of the three by 200 m polymer stabilised sections were found to be in good condition as they showed distortion free surfaces. This was in contrast to the badly rutted and rock-strewn condition of the adjoining control sections after being subjected to traffic for only four months (Polymer Pavements, 2010).

SoilTech Mk III polymer (polymer used in conducting this research) has been widely used in South Africa, Australia, India and in the U.S.A, especially in the state of California and is extensively used by the U.S Military in the Middle East conflicts as a product that is fast and highly reliable (IPPL, 2010). It is manufactured in Delhi, India by Polymer Pavements. Polymer Pavements has offices in South Africa, India and Canada (Polymer Pavements, 2010).

### 1.2 Problem Statement

Despite having many years of experience with the stabilisation of gravel for use in road construction and comprehensive specifications based on this experience, a noticeable increase in problems related to...
road material stabilisation is taking place in Zimbabwe, resulting in serious cost increases. As chemical stabilisation is being increasingly used to improve the quality of sub-standard road pavement materials and to recycle old pavement materials in Zimbabwe, the number of problems seems to be increasing correspondingly. For example, cement has its shortcomings which are; cement additives may result in the development of a fully bound cement treated base layer and therefore due to stiffness, transverse shrinkage cracks may develop along the pavement. There is also a poor performance of the pavements deriving from untimely cracking and deterioration of the cemented base layer. Generally, all lime stabilised fine-grained soils exhibit reduced plasticity and decreased volume change features and therefore there is need to investigate the use of polymeric stabilisers if they are additives of superior quality and at a viable cost to road construction. The costs of using conventional ways of stabilising the soil are still high. Moreover, the fast pace at which technology is emerging and changing worldwide has led to a boom of what are usually termed “non-conventional” soil stabilisers or additives (e.g. polymers) in the road construction sector within the SADC region. These “non-conventional” stabilisers are of low cost and are usually claimed to be very effective by the manufacturers as an alternative to the conventional stabilisation.

2 Soil Stabilisation Methods

2.1 Soil Stabilisation

Soil stabilisation is the process of blending and mixing materials with soil to improve certain properties of the soil. The process may include the blending of soils to achieve a desired gradation or the mixing of commercially available additives that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil (Guyer, 2011). These include mechanical stabilisation which can be accomplished by the mixing or the blending of two or more gradations to obtain a material of required specification and additive stabilisation which is achieved by the addition of proper percentages of polymers, cement, lime, fly ash, bitumen, or combinations of these materials to the soil. As stated by DFID (2000), the strength of a stabilised soil depends on a number of factors which include: the chemical composition of the soil to be stabilised; the stabiliser content; the degree of compaction attained; the moisture content; the ability of mixing the material correctly with the stabiliser and the consequent external environmental effects. For successful stabilisation, the soil should be capable of sustaining the applied loads without deformation and should retain its strength and stability indefinitely (DFID, 2000).

2.2 Polymer Stabilisation

India Polyroads Private Limited (IPPL) (2010) defines polymers as materials characterised by long chains of repeated molecular units and give the plastic amorphous structure having good impact strength and toughness. According to Wilmot(1994), polymeric stabilisers are found as either powder (with an appearance similar to that of finely ground cement) or liquid. The polymer acts by attaching itself to the fines thereby repelling water from the fines. By repelling water, the polymeric stabiliser greatly reduces capillary rise, increases soaked CBR values, increases wet strength and reduces permeability and therefore reduction in pore pressure maintaining characteristics of the dry material through wet conditions (Wilmot, 1994).

Stabilisation with polymers reduces the likelihood of rutting of the road pavement after periods of wet conditions. In some instances where the road pavement is left unsealed, a stabilising polymer can be sprayed over the existing stabilised road as a cost effective interim measure (AustStab, 2007). ECOroads, Polyroads, SoilTech Mk III and Probase are some examples of polymer stabilisers supplied for research courtesy of the Ministry of Transport and Infrastructural Development, Zimbabwe). From
studies by (Polyroads (2010); IPPL (2010) and Polymer Pavements (2010)) the advantages of polymer stabilisers include low cost, good resistance to corrosion and deterioration, resistance to water penetration and resistance to damage from freeze-thaw.

2.3 SoilTech Mk III Stabiliser

SoilTech Mk III is a polymer which uses water as a carrier to lubricate the fine particles at molecular level which under mechanical compaction get interlocked (IPPL, 2010). SoilTech Mk III is a blackish liquid with a particle that is 0.5µm in size (Polymer Pavements, 2010). The stabiliser is used for stabilising the base and sub base layers of roads; mine haul roads, parking lots, and hard stand and container depots (Polymer Pavements, 2010). It gains more strength from mechanical compaction. A road stabilised with SoilTech Mk III can have a design life of up to 20 years, subject to regular maintenance. Polymer stabilisers are immensely more environmentally friendly in terms of carbon emission than traditional layered, cement stabilised roads. Reports have shown that one kilometre of cement stabilized road, seven meters wide, will produce 50,449 tons of carbon into the air as opposed to 1,217 tons produced by SoilTech Mk III (Polyroads, 2010).

2.4 Pavement Condition Survey

Michigan Technical University (2014) defines pavement condition survey as the process of gathering information to establish the structural reliability, distresses, skid resistance, and overall riding quality of the road pavement. The existing gravel road condition reflects the factors affecting its performance. These factors may include gravel quality, pavement bearing capacity, moisture regime and drainage. For example, sections which are severely distressed are often located in areas where there is gravel of poor quality. They could also be caused due to poor road drainage (Pinard M., 2013).

2.4.1 Types of Pavement Condition Surveys

These include distress survey, structural capacity survey, roughness (ride quality) survey and skid resistance (surface friction) survey (Michigan Technical University, 2014). For this project, a visual assessment of the existing road was carried out to obtain the general condition of the road. This was accomplished by spotting any weak areas and isolated failures that need rectification prior to the construction of the pavement layer(s) and surfacing.

2.5 Background of ECOroads

The Ministry of Transport and Infrastructural Development of Zimbabwe (MOTID) conducted a pilot project on the use of polymer stabilisers on a trial section at Chivake, Zimbabwe. A road section of 4 kilometres was identified on Chivake Detour at the 70 kilometre peg off Harare – Murewa Highway. The literature on ECOroads states that it is a patent-pending complex non-bacterial, concentrated, multi-enzymatic formulation that alters the properties of earth materials and increases the strength, density and durability of roads and road bases (MOTID, 2011; Polyroads, 2010). It provides one of the most cost-effective methods to construct or stabilize roads and road bases. While enzymes are a core part of the ECOroads formulation, the product contains additional organic compounds designed to accelerate bonding of ionic, charged soil particles (MOTID, 2011; Polyroads, 2010). ECOroads increases the soil bearing characteristics by promoting a closer binding of soil particles. This reduces the tendency of the soil to expand after compaction and results in a strong, stable earth layer that resists the migration of water. Enzymes increase the compressive strength of soil. The enzymes act as a catalyst to accelerate and strengthen road material bonding, creating a denser, cohesive and stable soil. Enzymes also reduce the compaction effort and improve soil workability while lubricating the soil particles (MOTID, 2011; Polyroads, 2010). From studies by MOTID (2011) it is recommended that when treating soils with ECOroads stabiliser, it is recommended that the completed course be uniformly treated free from loose
rock or hence segregated areas of uniform density and moisture content, for its depth and shall have a smooth surface.

2.6 ECOroads Trial Section on Mdeka-Kammamba Road Section, Malawi

Trial sections of pavement were tested in Malawi on the Mdeka-Kammamba Road and it was observed that use of ECOroads increased the California Bearing Ratio of the material and also the maximum dry density. The liquid limit for the stabilised soil decreased with a decrease in plasticity index (PI). The results are shown in Table 1.

Table 1 Results of tests conducted on the trial section on Mdeka-Kammamba Road Section in Malawi

<table>
<thead>
<tr>
<th></th>
<th>Maximum Dry Density</th>
<th>Optimum moisture content</th>
<th>Liquid limit (LL)</th>
<th>Plasticity Index (PI)</th>
<th>CBR at 95%</th>
<th>CBR at 98%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unstabilised soil</td>
<td>1739 kg/m³</td>
<td>17.0%</td>
<td>49%</td>
<td>27%</td>
<td>23</td>
<td>31</td>
</tr>
<tr>
<td>Stabilised soil</td>
<td>2113 kg/m³</td>
<td>10.0%</td>
<td>33%</td>
<td>16%</td>
<td>30</td>
<td>39</td>
</tr>
</tbody>
</table>

3 Materials and Methods

3.1 Study Area

The location of the project site was Shamva, Mashonaland East province in Zimbabwe where Christian road (route 114) is located. The road is 6.3km long but for the purposes of this project, a 2 km length was considered. The route follows an approximate west to east direction and the considered 2 km distance beginning at the Shamva road/Christian road intersection. The site map and the location of trial pits is shown in Figure 1.

Figure 1 Picture showing the positions of Shamva road; Christian road; Stock pile and DCP points 1, 2 & 3 (Source: Surveyor General’s Office edited by authors)
3.2 Visual Road Condition Assessment

Deposited sand and gravel was observed at the edge of the road indicating that there was some gravel loss due to looseness of the gravel. Short wavelength, high frequency and low amplitude gullies which been caused by erosion due to poor drainage were observed. These shallow gullies can set up oscillations in a vehicle travelling over the surface thereby making the road user uncomfortable. The gullies are more pronounced on the shoulders of the road as can be seen in Figure 2. On the 50 m pavement surface done by the Ministry of Transport and Infrastructural Development, Zimbabwe in 2011 (testing EcoRoads), the pavement was discovered to be uneven with evidence of settlement caused by poor and uneven compaction as illustrated in Figure 2.

![Gully](image)

**Figure 2:** Photograph showing some of the shallow gullies and uneven road pavement (By Authors)

3.2 Application of Stabiliser

The ECOroads product was tested by the Ministry of Transport and Infrastructural Development in July 2011, on a 50 metre stretch of Christian Road, Shamva. Dynamic Cone Penetrometer (DCP) tests and visual condition survey tests carried on Christian Road, indicated that the ECOroads soil stabiliser was performing well. To ascertain whether the product is commercially viable for extensive use in Zimbabwe, the Ministry agreed to test ECOroads soil stabiliser over a longer stretches of road in different climatic conditions and soil types. The Department of Roads Research Team, Central Roads Laboratory and Palo Holdings came up with requirements to the government for funding by Zimbabwe National Road Authority (ZINARA). A road section of 4 kilometres was identified on Chivake Detour at the 70 kilometre peg off Harare – Murewa Highway. The stabilising agent was applied to the imported soil on the road and both field and laboratory investigations were carried out on the performance of the stabilising agent.

3.2 Dynamic Cone Penetration Test (DPC)

The Dynamic Cone Penetrometer (DCP) is an instrument designed for the quick in situ determination of the structural properties of existing road pavements that have unbound granular materials. Continuous measurements can be made to a depth of 800 mm or to 1200 mm when an extension rod is fitted. The cone penetration rate when driven by a standard force is proportional to the strength of the soil. The boundaries of pavement layers with different strengths can be identified hence the thickness of the layers can be determined. (TRL, 1993). The DCP is operated by three people one to hold the instrument, the other to raise and drop the weight and a technician to record the results.
3.3 Laboratory Tests

3.3.1 Soil classification Tests

Soils are classified by Engineers according to particle size instead of their age, origin or mineral constituents. According to the British Standard BS5930 (1999), the basic soil types are boulders, cobbles, gravel, sand, silt and clay. These types of soils are defined according to the particle size ranges with clay soil having particle sizes less than 0.002 mm, silt soil from 0.002 to 0.06 mm, sand soil from 0.06 to 2 mm and gravel soil from 2 to 60 mm. The particle size analysis of the soil is carried out using the sieve analysis test as described in (SAZ 185: Part 1:1998 (or ZWS185). The soil indicator tests are used to classify the soil using the liquid limit and plastic limit values of the soil. Shahjahan (2010) illustrates that the liquid limit and plastic limit tests can only be carried out on that part of soils which go through the 425 micron sieve.

3.3.2 Compaction

Compaction as the packing together of soil particles with the expulsion of air only (Craig, 2004). In the field, it is accomplished rolling, ramming or vibration and results in the decrease in the volume of voids and in the density of a soil. The extent of compaction is measured in terms of dry density i.e. the mass of solids per unit volume of soil. The maximum dry density and the optimum moisture content for each soil sample were determined and these were used to assess the degree of compaction in the field.

3.3.4 Direct Shear Stress Test

Craig (2004) defines shear strength as the capacity of the soil to resist shearing stresses. Direct shear stress test is generally executed because the majority of soils are visco-elastic (soil failures depend on time). In the design of roads, foundations and all designs relating to earthworks and slope stability subjects, the soil in question is required to withstand the shearing stresses together with compressive stresses. According to Shahjahan (2010), the shear box test is very simple and easy and can be carried out in a short period of time. The shearing resistance of the soil is a very significant factor in the design of earth slopes for the highway embankments. Therefore, the shearing of foundation soil can lead to complete road pavement disintegration and loss of embankment through sliding. The shear box test is used to establish the residual shear strength parameters for the analysis of pre–existing slope instability (Skempton 1964; Skempton and Petley 1967, cited in Shahjahan (2010)). It is most appropriate for dry and saturated soils that are not cohesive but can be used on all soils.

3.4 Pavement Design Procedure

The design calculations and procedures are shown in Table 2.

Table 2 Design calculations and procedures

<table>
<thead>
<tr>
<th>Reference</th>
<th>Calculations</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOTC Construction Manual Part F, 1978 Clause 20.2.1</td>
<td>Assumptions</td>
<td></td>
</tr>
<tr>
<td>a) The road is to be built on a granitic formation as shown in Appendix E. Soil data obtained from the samples taken from the stock pile are shown in Appendix B.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) The growth rate of 5% per annum was used and the mean 80KN equivalency axle factor is 0.256. The growth rate was chosen as 5% per annum because the Christian road connects two highways (i.e. Murewa road and Shamva road) and therefore there is anticipated increase in vehicles using this road to connect these highways if the Christian road is in a good condition. Also, there is a botanical garden along</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| the Christian road (3km from Shamva road) therefore there is anticipated increase in traffic due to tourists visiting the garden.  
c) The regional adjustment factor is 1.0.  
d) The design life of the road is 20 years.  
e) The road will have two surfaced lanes |

| **Estimating Traffic flows and volumes** |
| Traffic counts are performed with the objective of determining the axle load.  
Traffic counts are done over a long period of time (for the purposes of estimating traffic flow) to prevent producing estimates which have very large errors since there can be huge daily, weekly, monthly and seasonal traffic variations.  
Traffic counts can be obtained from existing traffic count information, and should take cognisance of the prospect for diverted traffic (existing traffic that changes from another course) and generated traffic (additional traffic generated from the development).  
For this project, the traffic counts were done and only one vehicle (with 2 axles) passed indicating that the road was used by very low traffic due to its poor state. No other traffic counts were done on this road before. Because of this, traffic counts of Marondera-Chiduku road obtained from the Ministry of Transport were used. |

| **Determination of cumulative equivalent standard axles** |
| The average cumulative traffic per day is determined with the intention of estimating the appropriate design axle load.  
Total No. of axles per day = \( axles\ per\ vehicle \times No.\ of\ vehicles\ (E80) \)  
Total No. of equivalent axles per day = \( No.\ of\ axles\ per\ day \times equivalecy\ factor\ (E80) \)  
Allowing a one year’s growth rate at 5% per annum between traffic survey and opening of the road to traffic:  
\[ \text{Total No. of equivalent axles per day at opening} = 1.05 \times equivalecy\ factor\ (E80) \]  
Total equivalent axles in both directions in 20 years = \( Total\ axles\ per\ day\ at\ opening \times design\ factor \)  
Since the road has two surfaced lanes: |
: Total equivalent axles in one direction = Total equivalent axles in both directions/2 (E80)

The climatic factor is given as 1.0 and therefore no allowance for climate is made.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sizing of Pavilion Layers</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>(SATCC, 2001), Table 2.5</td>
<td>From the design traffic in table 2 in Appendix A, the traffic class designation is determined.</td>
<td>The traffic class designation is T3</td>
</tr>
<tr>
<td>(SATCC, 2001), Table 3.1</td>
<td>The LCE results were used in determination of the thickness of the pavement of the unstabilised soil.</td>
<td>The subgrade class is S5</td>
</tr>
<tr>
<td>(SATCC, 2001), Table 3.3</td>
<td>The subgrade class designation gives the recommended minimum depth of the pavement.</td>
<td>The minimum depth is 550 mm</td>
</tr>
<tr>
<td>(SATCC, 2001), Chart W1</td>
<td>The surface dressing or hot mix asphalt depth is indicated. There are going to be three bases</td>
<td>Surface dressing = 50 mm</td>
</tr>
<tr>
<td>(Polymer Pavements, 2010)</td>
<td>For the pavement with stabilised material, surface dressing and only one base is provided.</td>
<td>Base 1 = 150 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Polymer Pavements, 2010)</td>
<td>Base 2 = 150 mm</td>
</tr>
<tr>
<td>(Polymer Pavements, 2010)</td>
<td>Base 3 = 200 mm</td>
</tr>
<tr>
<td>(Polymer Pavements, 2010)</td>
<td>Surface dressing = 50 mm</td>
</tr>
<tr>
<td>(Polymer Pavements, 2010)</td>
<td>Base 1 = 150 mm</td>
</tr>
</tbody>
</table>

### 4 Results and Discussions

#### 4.1 Dynamic Cone Penetration (DCP)

Dynamic cone penetration was carried out on the 14th of January 2014 and the ground was relatively dry. The DCP was done on three different points of the existing road at a spacing of 300 m apart.

The results obtained at point 1 show that the CBR is almost constant at an average of 75% for the tested depth of 150 mm of the road. This shows that the sub base of the pavement is compacted properly.
From the results above, the penetration per blow at point 2 decreases as the DCP cone moves down the 150 mm layer of the existing road tested. The decrease in penetration per blow shows an increase in the CBR value from an average of 75% to an average of 88%. These different values of CBR indicate that the bottom soils are better quality in terms of strength or it is compacted properly than the top ones. The following errors may have been encountered during the experiment i.e.: parallax error in reading the tape measure, failing to lift the sliding mass up the full length and not placing the cone Penetrometer on a level ground during measuring.

4.2 Compaction results

The dry density was determined for every sample mould and then graphs were drawn to estimate the maximum dry density of the soil at optimum moisture content. 7 kg portions of the soil sample were prepared according to Part 1 of BS1399 Standard were used. The material passing 26.5 mm BS sieve was used.

4.2.1 High Compaction Effort (H.C.E)

The compactive effort was kept constant at 2600 KJ/m$^3$ and the water content varied. The H.C.E was used to obtain the maximum density and optimum density of the soil that was used in determining the CBR of the polymer stabilised. In this test, a maximum of four portions of the soil sample were used. The results are shown in Figure 3.

![High Compact Effort](image)

**Figure 3:** Results of Compaction Tests for the High Compactive Effort (HCE)

Maximum dry density = 2120 kg/m$^3$

Optimum moisture content = 6.7 $\approx$ 7.0%

4.2.2 Low Compaction Effort (LCE)

A compactive effort of 570 KJ/m$^3$ was used and the water content varied. The H.C.E was used to determine the density of the lower layers of the road i.e. the roadbed, fill and selected subgrade. In this
test, a maximum of four portions of the sample were used. The results of the compaction tests are shown in Figure 4.

![Low Compaction Effort](image)

**Figure 4**: Results of Compaction Tests for the Low Compactive Effort (LCE)

Maximum dry density = 2014 kg/m$^3$

Optimum moisture content = 9.6 %

4.2.3 High Compaction Test (H.C.E) for Unstabilised soil (at optimum moisture content)

This test was carried out to compare the dry densities of the soil portions with those stabilized by SoilTechMkIII under the same moisture content (of 7%) and compactive effort (of 2600KJ/m$^3$). After four days of immersion of the moulds in water, the moisture content was found to be at an average of 7.2% and a maximum dry density of 2210 kg/m$^3$.

4.2.4 H.C.E Test for Stabilised material (at Optimum moisture content)

The following H.C.E test was done using stabilized portions of the soil sample at optimum moisture content of 7 % and a constant compactive effort of 2600 KJ/m$^3$. After four days of immersion in water, the moisture content was also found to be at an average of 7.2% and a maximum dry density of 2260 kg/m$^3$. The results using different proportions of stabiliser are shown in Figure 5 which also shows the comparison between the stabilised material and the unstabilised material done at optimum moisture content.
4.2.5 Observation and Discussion of Results

From the results, stabilised soil has a very high maximum dry density of 2365 kg/m$^3$ at an optimum moisture content of 7.2% as compared to the unstabilised sample which has a maximum dry density of 2116 kg/m$^3$. This shows that SoilTechMkIII increases the maximum dry density of the soil. The optimum of moisture content of the stabilized sample increased with 0.2% from the optimum moisture content which was determined in the H.C.E test of the unstabilised sample.

Shahjahan (2010) observed that the CBR test has another weakness and the weakness is that the test can not be performed if the particle sizes are over 20 mm. Lee & Bindra (1981) and Brown (1981) cited in (Shahjahan, 2010), also observed that the CBR test does not give the resilient behaviour of soil materials that is needed for pavement design. The CBR was very low at 3%. Values of CBR in the range 3 to 7% are considered to be poorly inconsistent. Therefore the soil sample can be considered to be poorly inconsistent with respect to CBR value classification.

Table 3 shows the summary of the CBR test results of the unstabilised portions.

**Table 3** Summary for the CBR of unstabilised portions

<table>
<thead>
<tr>
<th>Dry Density</th>
<th>CBR %</th>
<th>Moisture Content at Compaction %</th>
<th>Moisture Content After Compaction %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2044</td>
<td>84.4</td>
<td>6.7</td>
<td>9.3</td>
</tr>
<tr>
<td>2111</td>
<td>60.9</td>
<td>7.8</td>
<td>10.9</td>
</tr>
<tr>
<td>2104</td>
<td>83.5</td>
<td>7.3</td>
<td>23.6</td>
</tr>
</tbody>
</table>

The variation of CBR with moisture content is shown in Figure 6.
For optimum moisture content of 7% and using the graph of CBR/Moisture content above, the maximum CBR at optimum moisture content is 87%. Errors could have been encountered on mould 43 as it gave a very low CBR of 60% as compared to the other CBRs obtained in other moulds.

The graph above shows the comparison of the CBR of the unstabilised sample and the stabilised sample.

4.2.6 Sieve Analysis Results

From the results the soil is generally well graded as the distribution curve looks flatter. The effective size $D_{10} = 0 \text{ mm}$, $D_{30} = 0.15 \text{ mm}$ and $D_{60} = 0.19 \text{ mm}$. Therefore, as observed the soil ranges from sandy to gravelly sizes.

4.2.7 Index Test-Natural Soil

The liquid limit of the natural soil was 23.3% and the average plastic limit was 15.3%. The plasticity index was 8%. The P.I indexes 8 and therefore the soil sample is in the range for optimum binding as stated in Polymer Pavements (2010) that the range of P.I should range between 7 and 17 for optimum binding.

4.2.8 Linear Shrinkage Test

\[
\text{Shrinkage} = \frac{\text{Shrinkage length}}{\text{Length before drying}} \times 100\%
\]

The results of the shrinkage limit test are shown in Table 4.
Table 4 Shrinkage Limit Test on the soil sample

<table>
<thead>
<tr>
<th>Mould No.</th>
<th>Length before drying (mm)</th>
<th>Length after drying (mm)</th>
<th>Shrinkage Length (mm)</th>
<th>Shrinkage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>39</td>
<td>150</td>
<td>147</td>
<td>3</td>
<td>(3/150)*100 = 2%</td>
</tr>
<tr>
<td>X1</td>
<td>150</td>
<td>146</td>
<td>4</td>
<td>(4/150)*100 = 2.7%</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td>0.5*(2+2.7) = 2.35%</td>
</tr>
</tbody>
</table>

Therefore the soil is not an expansive soil.

4.2.9 Shear Box Test

Table 5 shows the results of the shear box test carried out on the soil sample.

Table 5 Summary of Shear Box Test Results

<table>
<thead>
<tr>
<th>Loading (kg)</th>
<th>Normal stress at failure (kN/m²)</th>
<th>Shear Stress at Failure (kN/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>380.16</td>
<td>177.08</td>
</tr>
<tr>
<td>15</td>
<td>517.7</td>
<td>216.04</td>
</tr>
<tr>
<td>20</td>
<td>655.27</td>
<td>247.92</td>
</tr>
</tbody>
</table>

From the results the soil cohesion is $c = 80.4$ kN/m² and the angle of shearing resistance $\varphi$ is 14.4°. Therefore the soil has some clay particles as shown by the soil cohesion.

4.3 Chivake Project Results

4.3.1 Compaction Test Results

The Ministry of Transport and Infrastructural Development of Zimbabwe (MOTID) conducted a pilot project on the use of polymer stabilisers on a trial section at Chivake, Zimbabwe. The soils are mainly sandy and have some essentially ferrallitic characteristics, but which are not strictly ferrallitic. The site is underlain by greyish brown coarse grained sands over pale loamy sands and occasionally sandy clays; clay fraction is essentially ferrallitic (no 2:1 lattice minerals), but reserves of weatherable minerals are appreciable, formed on granitic rocks. The maximum dry density using the HCE for the unstabilised material was 1895 kg/m³ and the optimum moisture content was 15.8%. However after stabilisation the maximum dry density was 1975 kg/m³ and the optimum moisture content was 11.4%. The stabiliser had the effect of increasing the dry density of the soil and reducing the moisture content.

4.3.2 California Bearing Ratio Test (CBR) Results

The California Bearing Ratio values (CBR) for the untreated pavement are shown in Table 6. An average value of 33% was obtained.
Table 6 California Bearing Ratio for the unstabilised soil

<table>
<thead>
<tr>
<th>Pavement Position – Right Lane</th>
<th>Chainage/ KM</th>
<th>California Bearing Ratio (CBR)/ %</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>70 + 1.750</td>
<td>33</td>
</tr>
<tr>
<td>8</td>
<td>70 + 2.000</td>
<td>25</td>
</tr>
<tr>
<td>9</td>
<td>70 + 2.250</td>
<td>34</td>
</tr>
<tr>
<td>10</td>
<td>70 + 2.500</td>
<td>44</td>
</tr>
</tbody>
</table>

The CBR values for the stabilised soil are shown in Table 7. There is a marked increase in CBR after stabilisation. The highest CBR is obtained at the centre of the pavement and CBR increases markedly with time.

Table 7 California Bearing Ratio values for the stabilised soil three weeks and ten weeks after treatment

<table>
<thead>
<tr>
<th>Pavement Position</th>
<th>Chainage (km)</th>
<th>California Bearing Ratio at 3 weeks (CBR)/ %</th>
<th>California Bearing Ratio at 10 weeks (CBR)/ %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left Centre Right</td>
<td>Left Centre Right</td>
<td>Left Centre Right</td>
</tr>
<tr>
<td>1</td>
<td>70 + 0.250</td>
<td>49 29 48</td>
<td>50 50 33</td>
</tr>
<tr>
<td>2</td>
<td>70 + 0.500</td>
<td>39 50 46</td>
<td>50 40 50</td>
</tr>
<tr>
<td>3</td>
<td>70 + 0.750</td>
<td>23 50 48</td>
<td>33 50 50</td>
</tr>
<tr>
<td>4</td>
<td>70 + 1.000</td>
<td>47 48 46</td>
<td>50 50 40</td>
</tr>
<tr>
<td>5</td>
<td>70 + 1.250</td>
<td>44 42 50</td>
<td>50 50 50</td>
</tr>
<tr>
<td>6</td>
<td>70 + 1.500</td>
<td>39 16* _</td>
<td>50 50 8</td>
</tr>
<tr>
<td>7</td>
<td>70 + 1.750</td>
<td>_ _ 33</td>
<td>40 50 40</td>
</tr>
</tbody>
</table>

4.3.3 Visual Condition Survey Results

Table 8 shows the visual condition survey results for the Chivake Road.

Table 8 Visual Condition Survey Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rating</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrugation</td>
<td>2</td>
<td>Some sections show serious corrugation whilst others show good surfacing</td>
</tr>
<tr>
<td>Origin</td>
<td>1</td>
<td>Imported material</td>
</tr>
<tr>
<td>Cracking all</td>
<td>2</td>
<td>On sections where the imported material had very high PI</td>
</tr>
<tr>
<td>Maximum stone size</td>
<td>2</td>
<td>25-50 mm, oversize less than 5%</td>
</tr>
<tr>
<td>Structures</td>
<td>1</td>
<td>Structures in good conditions</td>
</tr>
<tr>
<td>Drainage</td>
<td>2</td>
<td>Some sections have good ditches whilst others have soil covering ditches. Culverts are in good condition</td>
</tr>
<tr>
<td>Roughness</td>
<td>2</td>
<td>3000 – 5000, A bit rough</td>
</tr>
<tr>
<td>--------------------</td>
<td>---</td>
<td>--------------------------</td>
</tr>
<tr>
<td>Overall condition</td>
<td>2</td>
<td>Fair</td>
</tr>
</tbody>
</table>

At Chivake detour 4 km trial section, ECOroads stabiliser was applied to imported soils because the existing pavement lacked plasticity. Costs in dumping soils were incurred, thus making construction with ECOroads soil stabiliser more costly compared to the conventional road construction method. Figure 10 shows photographs of the condition of the stabilised road in some sections of Chivake Road.

![Figure 10](image)

**Figure 10** Photographs showing the condition of the stabilised road in some sections

## 6 Conclusions and Recommendations

### 6.1 Conclusions

From the test carried out it can be seen SoilTechMkIII can be used for stabilisation even in highways as it increase the soil density and the soil bearing capacity. The soil in Shamva has high bearing capacity and can be used without stabilisation for the design of low volume roads. The bearing capacity of the existing road pavement increased with depth. The CBR increases after using the stabilisers and also increases with time.

ECOroads soil stabiliser works differently with different soil plasticity indices. ECOroads soil stabiliser works best with soils with plasticity indices in the range 10 – 15. At PIs below 10, road pavement failures (corrugations, roughness, reduction in binding ability) occur and at PIs above 15, crocodile cracks become prominent.

### 6.2 Recommendations

From the results of the research the following recommendations were made:

6.2.1. The tests need to be carried out on use of ECOroads over a three year period and on longer sections of the road so that the performance of the pavement after stabilization can be monitored.

6.2.2. It is recommended to stabilize the soil in order to increase its bearing capacity. It is also noted that the significance of mixing material thoroughly helps in coming out with more accurate results.
otherwise variable results are obtained. The soil sample can be stored in a sack for about half an hour so as to distribute the moisture in the whole sample to be compacted.

6.2.3 To overcome the difficulties of compacting particles of over 20 mm sizes, Lee and Bindra (1981) cited in (Shahjahan, 2010) proposed a Modified Bearing Ratio (MBR) test that allows aggregates up to 37.5 mm sizes in the compaction test. Equal distribution of blows and adding of equal mass per each layer is recommended. Table 1 shows the summary of CBR results on the stabilised soil samples.

6.2.4 When treating soils with ECOroads stabiliser, it is recommended that the completed course be uniformly treated free from loose rock or hence segregated areas of uniform density and moisture content, for its depth and shall have a smooth surface.

6.2.5 More trials on ECOroads be undertaken in different climatic conditions in Zimbabwe, being applied on in situ soils which fall within the required parameters (PI of 10 – 15) of soils that work best with ECOroads.

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3. Mr M. Caetano
4. Ms V. Dzawo

7.0 References

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