ROUGHTON INTERNATIONAL

In association with
THE UNIVERSITY OF BIRMINGHAM
and
THE UNIVERSITY OF NOTTINGHAM

Report VII
Soil Stabilisation Using Fibres

DFID Department for International Development

February 2000

Appropriate and Efficient Maintenance of Low Cost Rural Roads

Report VII
Soil Stabilisation Using Fibres

February 2000

The University of Nottingham
School of Civil Engineering
University Park
Nottingham
NG7 2RD
United Kingdom
www.nottingham.ac.uk/p&g

Roughton International.
321 Millbrook Road West
Southampton
SO15 OHW
United Kingdom
www.roughton.com

University of Birmingham
School of Civil Engineering
Edgbaston
Birmingham
B15 2TT
United Kingdom
www.bham.ac.uk/CivEng/

DFID Department for International Development

Department for International Development
94 Victoria Street
London
SW1E 5JL
www.dfid.gov.uk

Department for International Development
Knowledge and Research (KaR) Programme

Project Title:	Appropriate and Efficient Maintenance of Low Cost Rural Roads
DFID Project Reference:	R6852
Subsector:	*Transport*
Theme:	T2
Element D:	Investigation of Stabilisation Methods
Date:	*February 2000*

This document is an output from a project funded by the UK Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID

ACKNOWLEDGEMENTS

This report was prepared by Dr Gurmel S. Ghataora of the University of Birmingham with the help of Dr Imad Alobaidi, also of the University of Birmingham, who undertook the laboratory investigation in the UK.

The author is particularly grateful to Mr S. Bagonza, Chief Materials Engineer, Central Materials Laboratory, Ministry of Transport, Communication, and Public Works, Uganda for undertaking both the laboratory investigation and field trials.

The author is grateful to Mr A Ahmedi, Mr S Jones, Mr E C Bishop and Mr J D Redgers and RI Staff in Uganda for helping with the trials.

The author is grateful to Mr Tony Greening of Transport Research Laboratories for help and guidance in the preparation of the report.

Formatting and graphic design was undertaken by Mrs L Bailey, Mr J Charter and Ms A Horne (Roughton International Ltd).

EXECUTIVE SUMMARY

OBJECTIVES OF THIS ELEMENT OF THE PROJECT

Extract from the Research Proposal

This element involves a review of the use of fibrous and chemical (synthetic) stabilisers during road maintenance. A system to categorise materials and identify suitable additives for study will be conducted. A detailed laboratory study will be conducted in the UK using these materials and methods. Some overseas laboratory testing will be conducted where possible. Laboratory and full scale trials expect to reflect both the actual methods of repair used in practice, and the effect of alternative methods as well as in the interaction between material and method. An aim of the tests will be to produce a material which can be used for filling potholes, ruts or shoulders which will gain strength with modest compaction and establish some adhesion to the surrounding ground or original construction.

Whilst some testing of man made fibres will be included, the aim will be to identify natural, local fibres which could be used. If the use of man made fibres shows promise, then more effort will be put into locating and testing natural fibres.

The chemical stabilisation of marginal materials in areas of low material resources is being considered and tested on two of Roughton International's rural roads maintenance projects (Uganda and Nepal) and are expected to be of value to this project. Material recycling by using alternative additives as well as the more traditional lime and cement will be investigated.

An analysis will be conducted as to the usefulness and effectiveness of these methods and a recommendation of standards will be put forward to Progress Review Group. The final conclusion of this element will form a stand-alone report as well as part of the final guidelines for rural road maintenance.

Very early in the research it was realised that there was a lack of independent research information about these products. It was therefore agreed that only a database and notes for users should be produced for chemical stabilisers. It was agreed that standards would not be produced (as noted in the last paragraph).

Summary of the Work

Over the two years project programme only six months were available for the work on chemical soil stabilisers, review of case studies and fibre reinforced soils. This work was split into three parts:

Report 5

The first part of this element of the research concentrated on synthetic stabilisers. One of the objectives of the research was to form simpler methods of assessing the use of these stabilisers in the field. This could not be achieved due to great lack of independent research information and this research programme was too short to undertake detailed research for preparing simplified assessment methods. It was therefore decided to review the available information about these stabilisers, form a users guide and a database consisting of product composition, soil types for which they may be used, environmental issues and brief review of case studies. Thirty-eight products were reviewed for this part of the study.

Report 6

The second part of this element of the research concentrated on case studies. Two detailed reviews were conducted. Case study 1 related to the use of an enzyme stabiliser, UBIX 10, in Nepal for the construction of a mountain road. A researcher visited Nepal to observe the trials. He also undertook some monitoring tests to evaluate the success of the stabiliser.

Case Study 2 related to assessment of causes of failure of a trial section of road, stabilised with Terra-fix, constructed in Seychelles. This road failed (pot holes started to appear) a few years after construction. Field and laboratory test results from the trial construction were reviewed. Some laboratory tests were also conducted during this research to understand the causes of failure.

Report 7

The third part of this element of the research concentrated on the use of fibres for stabilising soils. This included both synthetic and natural fibres. Laboratory work was conducted on polypropylene fibres and both laboratory and field trials were conducted sisal fibre (natural fibre). Much of the work on using fibres was conducted in Uganda by the Ministry of Transport, Communication and Public Works. A field trial comprising construction of a road section was conducted on fibre reinforced laterite in Uganda.

The effect of three lengths (6, 12 and 18 mm) of polypropylene fibres at concentrations ranging from zero to 0.6% on the density, compressive strength and CBR of Oxford clay were investigated. The effect on density, UCS and CBR of 12 mm long sisal fibres ranging in concentrations from zero to 0.6% was investigated for laterite soil stabilised with lime and cement. The latter were at both 4 and 6% concentrations. Four, ten metre long section of road were constructed with reworked laterite, lime stabilised laterite and fibre reinforced and lime stabilised laterite. In the trials 12 mm long (nominal length) sisal fibres at 0.2 % concentration, and 4% lime were used.

The fibre reinforced cement stabilised study was a pilot investigation to assess suitability of this material for pothole repair. The effect of fibres on dry density, UCS and CBR were measured. A field trial was conducted in Uganda on repairing potholes with fibre reinforced cement stabilised lateritre.

Results of the Research

Report 5

The first part of this element of the study on stabilisers has clearly shown that there are a range of stabilisers that fall into two broad categories: sulphorated petroleum products and enzymes. The review of these products show that significant cost savings can be made if they are applied in the correct context. Discussions with practitioners show that failures can occur and these are due mainly to improper use of the stabilisers.

The database of 38 products provides an insight into the range of products. It is clear that the products are supported with different levels of information. Some care is therefore required in selecting a suitable stabiliser. The database allows a preliminary assessment of the stabilisers to be made. It also includes email and web site addresses. This database is available on compact disc.

Although all the manufacturers claim that savings could be made in the cost of construction and maintenance. It was difficult to make any judgement about this as costs would depend on the quantity of product used and where and how it was delivered.

General guidelines have been produced for using both sulphonated products and enzyme stabilisers.

Report 6

The second part of this element of the study on case studies shows that in the first case of a trial in Nepal failure occurred due to improper use of construction equipment and procedures. A report on the trial was sent to the manufacture for comment. He responded by saying that it would have taken a miracle for the stabiliser to work. He has however, offered to supply the product free of charge should it be possible to run another trial. Although the manufacturer's representative was present on site, the stabiliser was applied incorrectly with improper construction procedures.

For the second case study where a road was stabilised in Seychelles failure is thought to have occurred due to improper construction procedure. Suppliers or manufacturer of Terrafix could not be contacted to comment on the findings of the investigation.

Report 7

The third part of this element of the study on fibres showed that it was possible to use synthetic fibres to stabilise soils. They were however expensive. Work on sisal reinforcement showed potential and although a field trial on a road section worked well, it did not achieved its maximum potential as it was not possible to construct the road properly with the resources available. Nevertheless, it was shown that a poorly constructed fibre reinforced lime stabilised section performed as well as a well constructed lime stabilised or fibre reinforced road section.

Potholes trials showed that fibre reinforced cement stabilised laterite could be used to make repairs.

Implication of the Research

The results of the first part of the study did not achieve the objectives entirely due to lack of independent research information and lack of time to undertake extensive laboratory testing under the current programme. However, a general guidance note was prepared for using these stabilisers. A database that identifies at-a-glance the available products and some basic information about them was prepared. This included list of addresses and product names. This should enable the user to obtain more recent information about the products.

The two case studies have shown the pitfalls of using inappropriate construction equipment and procedures.

The work on fibre reinforced soils meets all the objectives set in the proposal. In the limited period of research it was possible to show that natural fibres may be used in road construction and pothole repair.

Recommendations and Future Work

This research project has uncovered a large quantity of information about chemical stabilisers. Most of this was however, supplied by the manufacturers promoting their products. There is a need to undertake independent research to evaluate the products. The results of the research will help the engineer to make objective decisions about the use of particular stabilisers.

A database of products showing soils for which they are best suited was prepared. However, there is a need to update the database to ensure that products that have proved unsuccessful in certain situations are highlighted and new ones are added. This information could be available on computer disc for distribution. Information about this could also be available on the Internet.

This work would be undertaken at the University of Birmingham with Roughton International. The former would be using their expertise already developed in this area and Roughton International would provide contacts and help to ensure that the database is end-user friendly by inputting the practitioners view.

This research has shown that fibres can be used to successfully reinforce soils for the construction of roads. The full potential of the field trials was not fully realised because suitable construction equipment was not available. It is therefore recommended that a larger research programme be undertaken to evaluate the fuller potential of using fibres in road construction. It is recommended that a laboratory study is followed by at least one field trial. In parallel with this it is proposed to develop low technology equipment excavating existing gravel roads and mixing in fibres. It is strongly recommended that bulk of this work is undertaken abroad. The University of Birmingham and Roughton International in collaboration with perhaps the materials laboratories in Uganda and Botswana and an equipment manufacturer would best conduct this research. The field trials could be conducted at one of Roughton International's contracts.

This proposed research would need to be for a three-year duration as field trials would need to be monitored for a prolonged period to assess durability of the stabilised soils.

Pilot study on pothole repair has also shown some potential. It is therefore suggested that this work is developed further in terms of a detailed laboratory investigation and field trials. It is suggested that this work is conducted in parallel to the study discussed above by the University of Birmingham, Roughton International and one or more overseas countries where fieldwork may be conducted.

Information from both the above studies would be presented at regional conferences so that it would be available to the users. Extracts of the report would also be published on the Internet.

REPORT VII - INVESTIGATION OF STABILISATION METHODS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHS

1. INTRODUCTION

The use of short lengths of a synthetic and a natural fibre for reinforcing clays was investigated and is reported in this part of the report. Laboratory investigation into the use of both fibre types in a clayey soil was undertaken at the University of Birmingham and is described in Section 1. This work was followed by a laboratory investigation and a field trial in Uganda on use of sisal in road construction and is described in Section 2 of this report.

A brief investigation into the use of fibre reinforced soil for pothole repair is also described in Section 2.

2. LABORATORY INVESTIGATION AT THE UNIVERSITY OF BIRMINGHAM

2.1 Background

With the advent of geosynthetic materials, their use in geotechnical and pavement applications has increased dramatically over the last two decades. Although, a considerable amount of research has been conducted on geotextiles, geomembranes and geocomposites, the research available on fibre reinforcement is limited. Nataraj and McMain (1997) showed found that the addition of fibrillated fibre to clay and sand did not change their compaction characteristic i.e. maximum dry density and optimum moisture content. Similar conclusion was arrived at by Al Wahab and Al-Qurna (1995). Fletcher and Humphries (1991) on the other hand showed that a modest increase in the maximum dry density and a slight decrease in optimum moisture content were observed with the increase of amount of fibre. Thus the effect of including fibres on the compaction characteristics of soils was not conclusive. It depended on the type of soil used and type of fibre used.

The compressive strength of soils increases considerably with the addition of fibre (Fretaig, 1986, Al Wahab and Al-Qurna, 1995). Fletcher and Hamphries (1991) reported a 100 % in CBR value due to addition of fibrilated fibre. One of the advantages of fibre is to limit the reduction in post peak strength (Gray and Ohashi, 1983).

Much research has been undertaken at the University of Birmingham on mixtures of synthetic fibres and clays by Dall'Acqua (1999). He showed that 12 mm of crimped fibres could be used to increase both the strength and strain to failure of clays. William (1998) showed the similar characteristics for fibre reinforced cement-bentonite slurry. Whilst these fibres worked well they were too expensive to be used in the construction and or maintenance of low cost rural roads. Thus an investigation into the use of sisal, a cheap natural fibre, was included in this study.

2.2 Aims

The aim of this pilot investigation was to assess the effect of adding short lengths a synthetic fibre and sisal fibre on the engineering properties of Oxford Clay.

2.3 Materials

2.3.1 Clay

Oxford Clay was used in this investigation, as it was available in large enough quantity to complete the test programme. Furthermore, it was used to give some indication of the behaviour natural clay when mixed with some sisal fibre.

2.4 Fibres

Two types of fibres were investigated. These are described below.

2.4.1 F120

AF120 was a straight, monofilament fibre made of polyester. It had a diameter of 50 μm and was 12 mm in length. It was developed for use in concrete. It was supplied by Fibrin (Humberside) Limited.

2.4.2 Sisal

Sisal is natural fibre that is obtained from leaves of the Agave Sisalana cactus plant, which grows in Central and Southern America and East Africa. Fibres of sisal are hard and slender. They exhibit great strength and resilience in the form of twine, cord and rope. Sisal is utilised in brake and clutch pads, in some thermoplastics, rugs, carpets, paper and a number of other products.

Sisal twine was trimmed to the required length manually. The fibres were cut to an accuracy of ± 1 mm. The fibres used ranged in diameter from 0.07 to 0.23 mm.

2.5 Laboratory Test Results and Discussion

All the laboratory tests were conducted in accordance with the British Standard, BS1377 (1990).

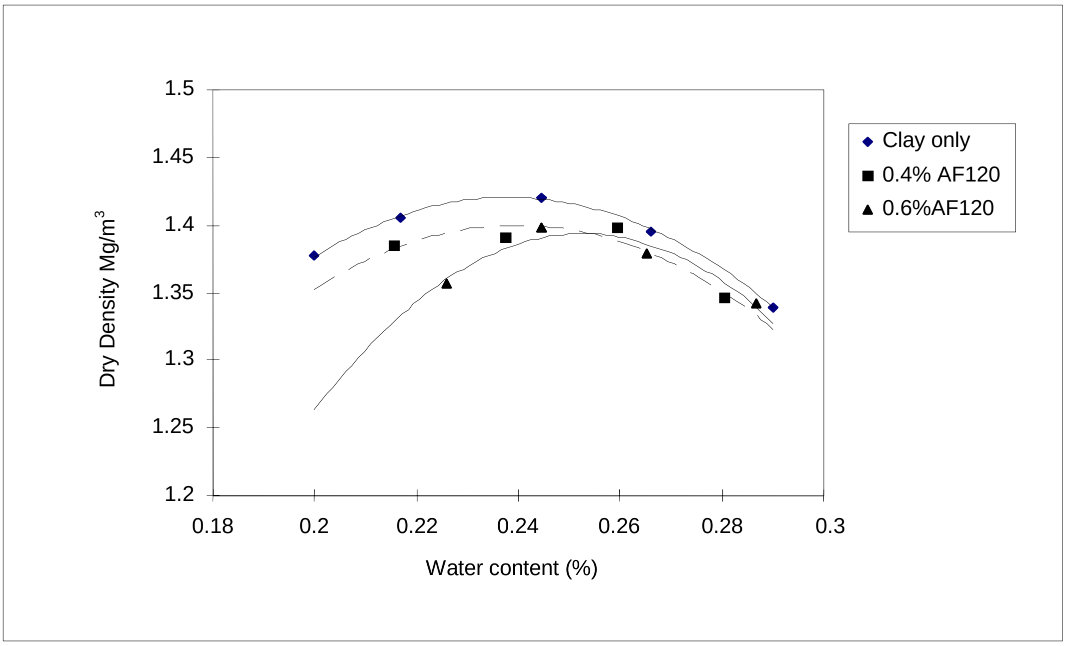
Samples were prepared by mixing dried and crushed soil with some of the required moisture. Fibres were mixed with the remaining water, which was then added to the soil. The mixture was stirred for about ten minutes until a homogeneous mix was achieved. A 4 litre capacity food mixer was used to prepare the mixes.

4.1 Compaction Characteristics

2.5.1 AF120

The dry density moisture content relationship of Oxford Clay at a range of fibre concentrations (from zero to 0.6%) is shown in Figure 2-1. There is a very small decrease in density at 0.4 % fibre content. Even with a 0.6 % fibre content there is a reduction of less than 2%. The moisture change with addition of fibre is within ± 1% of the value for unreinforced clay. This is as expected as the fibres were of similar density to that of water and in terms of weight only a small quantity is added. The change in moisture content is a little unexpected as fibres absorb a very small quantity of moisture.

Figure 2-1 Effect of Fibre on Dry Density and Moisture Content Relationship of Oxford Clay with Zero, 0.4 and 0.6% of F120 Fibre



2.5.2 Sisal

Compaction tests were conducted to ascertain the effect of adding sisal in concentrations ranging from 0.2 to 0 6% on the dry density and moisture content of Oxford Clay. Compaction tests were conducted in accordance with Part 4 of BS 1377:1990.

Results of dry density and moisture content relationship for 0.2, 0.4 and 0.6 % concentration is shown in Figure 2-2, Figure 2-3 and

Figure 2-4 respectively. Results show that in all cases addition of fibre results in a small, but not very significant, increase in maximum dry density and a small reduction in the optimum moisture content. It seems that the inclusion of fibre in the range of concentrations examined does not have a deleterious effect in terms of compaction.

Figure 2-2 Dry Density and Moisture Content Relationship for 6, 12 and 18 mm Long Sisal Fibres at 0.2% Concentration

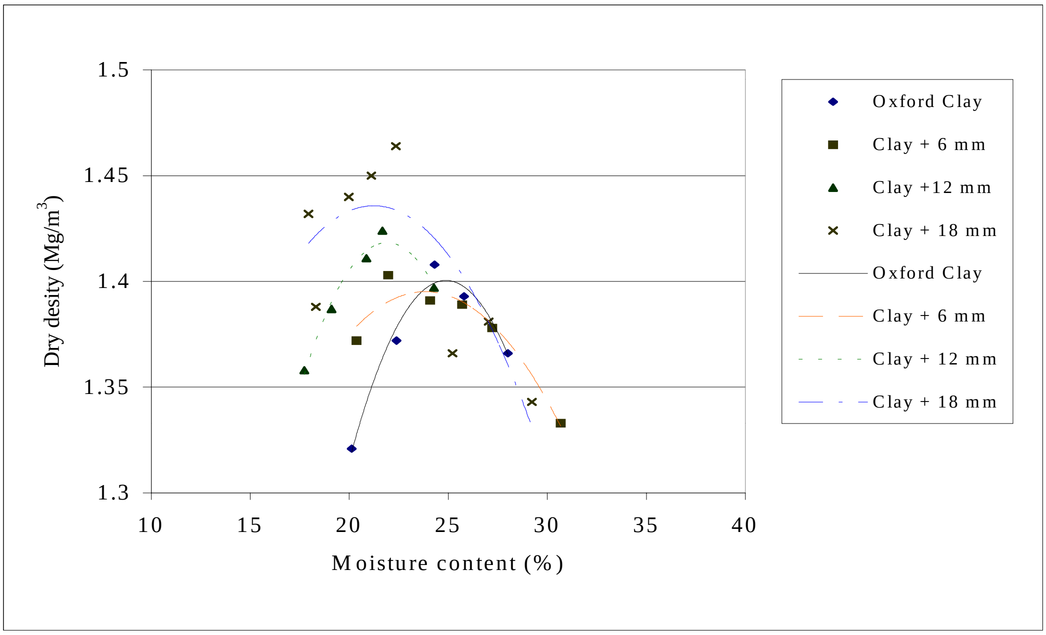


Figure 2-3 Dry Density and Moisture Content Relationship for 6, 12 and 18 mm Long Sisal Fibres at 0.4% Concentration

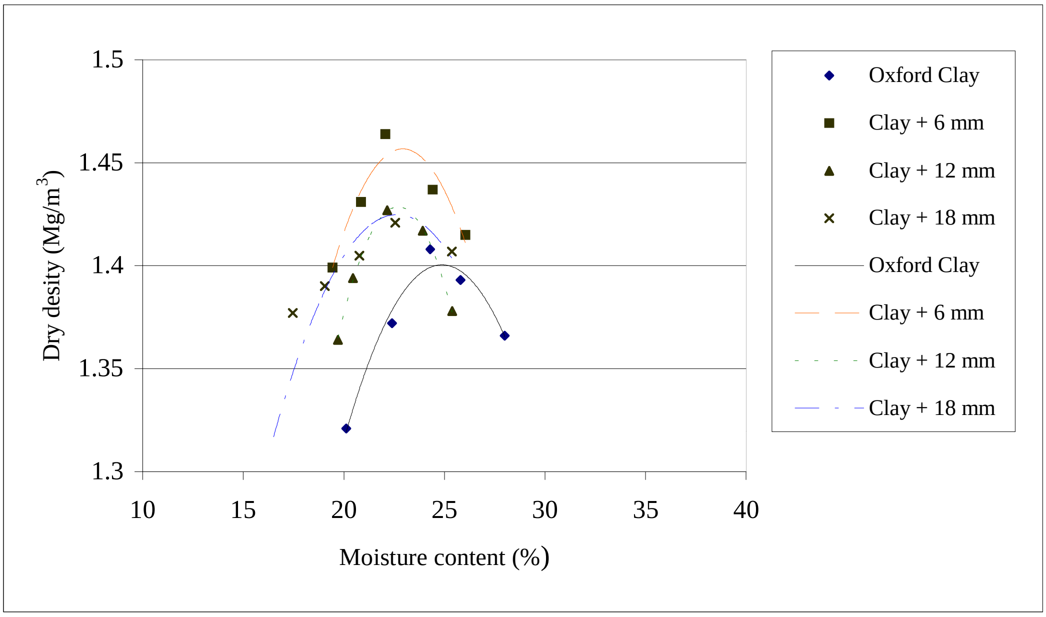
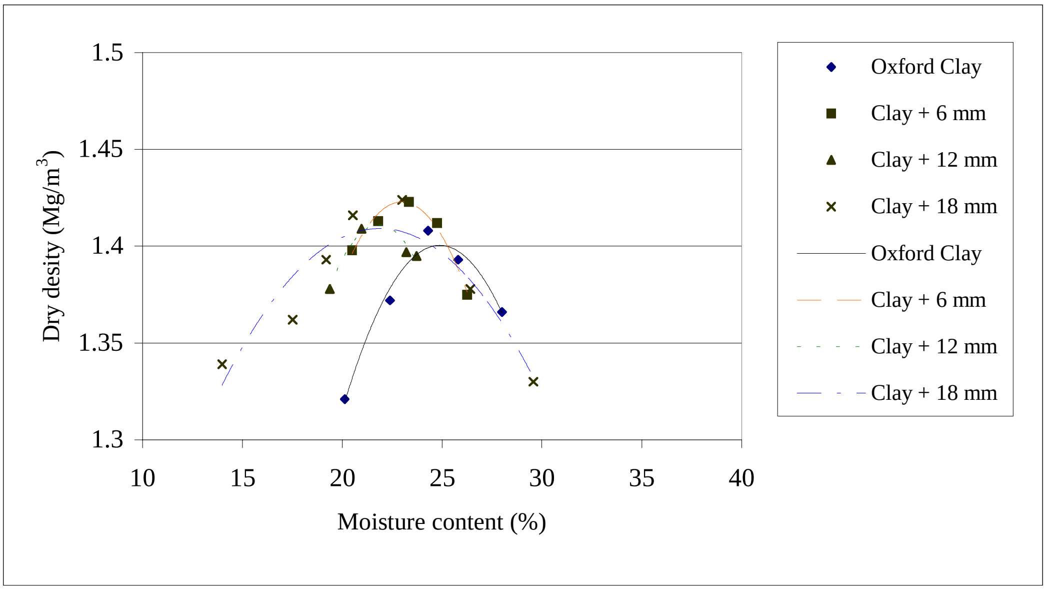


Figure 2-4 Dry Density and Moisture Content Relationship for 6, 12 and 18 mm Long Sisal Fibres at 0.6% Concentration



Maximum dry density (MDD) and optimum moisture content (OMC) for the different fibre concentrations and lengths are given in Table 2-1. Results show that there is a reduction in OMC of up to about 3 %. They also show that changes in MDD due to addition of fibres are small. Worst case is for 6mm long fibre at 0.2% concentration. All the other cases show a small, not very significant, increase in density.

Table 2-1 Effect of Sisal Fibre Concentration and Length on Optimum Moisture Content and Maximum Dry Density of Oxford Clay

Oxford Clay	**Optimum Moisture Content (25%)**			**Maximum Dry Density (1.4 Mg/m^3)**		
	Fibre length (mm)					
Fibre Concentration	**6**	**12**	**18**	**6**	**12**	**18**
0.2%	23	22	21	1.39	1.42	1.44
0.4%	22	22	22	1.46	1.43	1.425
0.6%	23	20	21	1.42	1.41	1.41

2.6 Strength Determinations

2.6.1 AF120

Unconfined compressive strength tests were conducted on Oxford Clay compacted at MDD with 0.4 % AF120 fibre. These tests were conducted in accordance with BS1377:1990:Part 8. Results show that there was a 25 % increase in strength when fibre was included. A typical stress strain relationship is shown in Figure 2-6 overleaf.

CBR tests were conducted on specimen compacted at their maximum dry density with zero, 0.2, 0.4 and 0.6 % fibre concentrations. Results are shown in There was no significant improvement in CBR with increase in fibre content. These results thus do not reflect the improvements observed for the UCS tests. This may be due the effect of confinement and the fact that the two tests invoke a different mode of failure.

Figure 2-5 Effect of 0.4 % AF120 Fibre of the Unconfined Stress Strain Behaviour of Oxford Clay

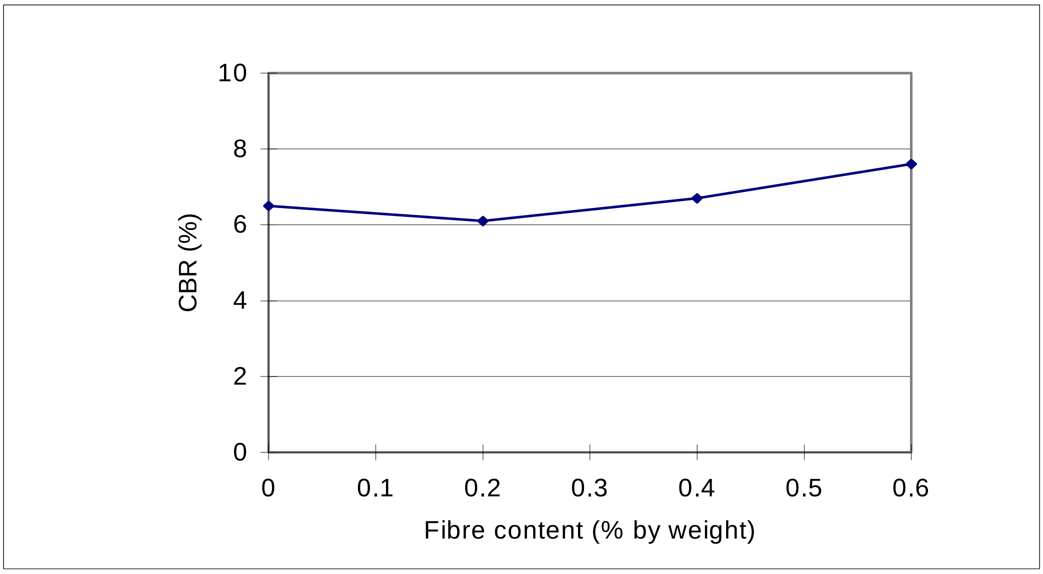
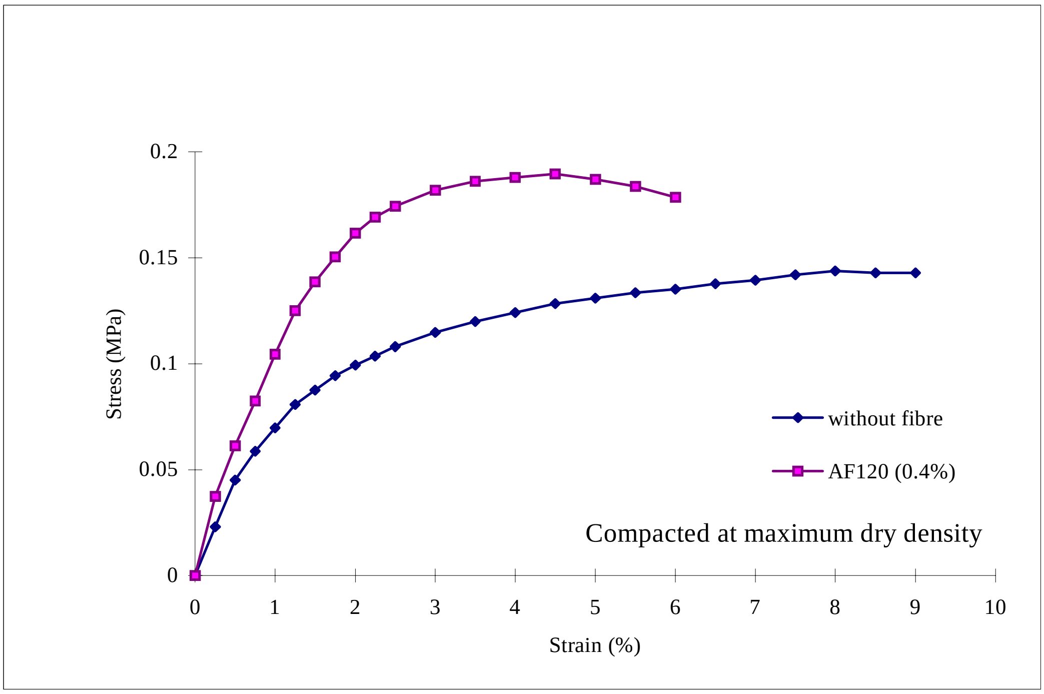


Figure 2-6 Effect of Concentration of AF120 on CBR of Oxford Clay



2.6.2 Sisal

Undrained shear strength of the fibre reinforced clay was determined by conducting undrained triaxial tests on 38 mm diameter specimen prepared at their MDD using static compaction. These tests were conducted in accordance with of BS1377:1990:Part 8. Confining pressures ranging from 50 to 250 kPa were applied. Results of all the triaxial tests are summarised in Table 2-2. Without any fibres Oxford Clay behaves as a cohesive material with a high value for apparent cohesion (144 kPa) and a low friction angle (degree). For 0.2% and 0.6 % fibre there is up to about 40 % reduction in cohesion but the angle of friction increases to between 16 and 22 degrees representing a 38 % increase. At 0.4 % fibre content there is a small reduction (about 3%) in cohesion and the angle of friction is in the same range as for other fibre contents. Fibre reinforced specimen also exhibit a small reduction in strain to failure compared to clay only samples. See Table 2-3. This behaviour is contrary to expectations as generally inclusion of fibres would have expected to increase strain to failure. It is apparent that inclusion of fibres has made the clay a more frictional material.

Table 2-2 Effect of Sisal Fibre Concentration and Length on Apparent Cohesion and Angle of Friction for Oxford Clay Determined using Quick Undrained Triaxial Rests

Oxford Clay	Apparent cohesion (c) 144 kPa			Angle of friction (ϕ) 1°		
	Fibre length (mm)					
Fibre Concentration	**6**	**12**	**18**	**6**	**12**	**18**
0.2%	80	105	86	18.5	18.5	22
0.4%	140	140	130	15.5	21	20
0.6%	67	100	100	18.5	18	16

Table 2-3 Effect of Sisal Fibre Concentration and Length on Strain to Failure for Oxford Clay Dtermined Uing Qick Undrained Triaxial Tests

Oxford Clay	Strain to failure 14.3%		
	Fibre length (mm)		
Fibre Concentration	**6**	**12**	**18**
0.2%	12.3	12.6	11.3
0.4%	8	12	10
0.6%	13	12	12.7

2.7 Conclusions

In the short time available for this investigation the effect of a synthetic fibre (AF120) and a natural fibre (sisal) on compaction and strength characteristic of Oxford Clay was ascertained. The following conclusions are made from this study.

i. AF120 did not have a significant effect of maximum dry density of the soil.

ii. Although inclusion of 0.4% AF120 resulted in a significant increase in the UCS of clay compacted at its maximum dry density there was little effect of CBR of the soil.

iii. Inclusion of sisal fibres from concentration of 0.2 to 0.6 % resulted in a small but not very significant increase in maximum dry density of the soil.

iv. Quick undrained triaxial tests on sisal reinforced Oxford Clay showed the material to have a lower cohesion and a higher value of friction angle compared to be plain clay.

2.8 Recommendations

This pilot investigation has shown that there are improvements in some of the engineering properties of clays reinforced with fibre. This is particularly significant for natural fibres as they are very cheap compared to synthetic fibres. It is thus strongly recommended that a more detailed assessment should be made of engineering properties of clay reinforced with natural fibres.

3. LABORATORY AND FIELD TRIALS IN UGANDA

3.1 Introduction

This work was undertaken over a three month period from October 1997 to August 1999. This was a pilot investigation to prove the viability of using sisal reinforced lime or cement stabilised laterite soil in road construction. Work in Uganda was undertaken by the Chief Materials Engineer of the Ministry of Works, Transport and Communication. It was supervised by the University of Birmingham.

A limited laboratory investigation was undertaken to show that inclusion of sisal fibres did not have a significantly adverse effect on the density of the soil and that when used with lime or cement significant gains would be made in performance to enable construction of a road-base and repair potholes. Subsequent to the laboratory investigation a small field trial was conducted to assess the constructability and performance of fibre reinforced lime stabilised section of gravel road.

A field trial was also undertaken to assess the suitability of fibre reinforced stabilised soil for pothole repair.

3.2 Laboratory Trials

3.2.1 Laterite

Local laterite was used in this investigation. The particle size distribution of this soil indicates it to be silty coarse sand to medium gravel sized, see Figure 3-1. It had a GM and PM of 855. The clay fraction was of intermediate plasticity (LL = 54 to 56, PL = 26 to 27 and PI = 27 to 29). It was classified as A-2-7 according to the AASHTO soil classification system and could be used as wearing course on unpaved gravel roads in the tropics.

Generally inclusion of fibres in soil will result in increase in both the compressive and tensile strengths of the soil and increase strain to failure. When fibres are added to a soil its mode of the failure changes from brittle to plastic. Increase in strength results from both interlocking of particles and cohesion of soil to fibres. Thus stresses can be transferred via the fibres to a larger mass of soil away from locations of stress concentrations. Therefore increased packing of particles will result in increase in strength, by improving the fibre-soil interlock, up to a limit where further increase can result in damage to the integrity of the fibre. There will be no further gain in strength beyond this point. There may indeed be a reduction. It was therefore decided to use British Standard heavy compaction in accordance with BS1377(1990), Part 4, to ascertain the dry density and moisture content relationship of the Laterite. Maximum dry density (MDD) of 2.15 Mg/m^3 was achieved at the optimum moisture content (OMC) of 9.7%.

3.3 Fibre Reinforcement

For clayey soils fibre provide resistance to shearing through cohesion soil particles and through interlocking. Hence the three essential properties of fibres which can be used for reinforcement of clay soils are smaller diameter, providing a large surface area per unit weight, high flexibility and high tensile strength. In this instance sisal was investigated as it has a reasonably high tensile strength and is possibly more durable than many other natural fibres of smaller diameter. It is however very rigid compared to other natural fibres. Sisal is also cultivated on a large scale and thus it is readily available.

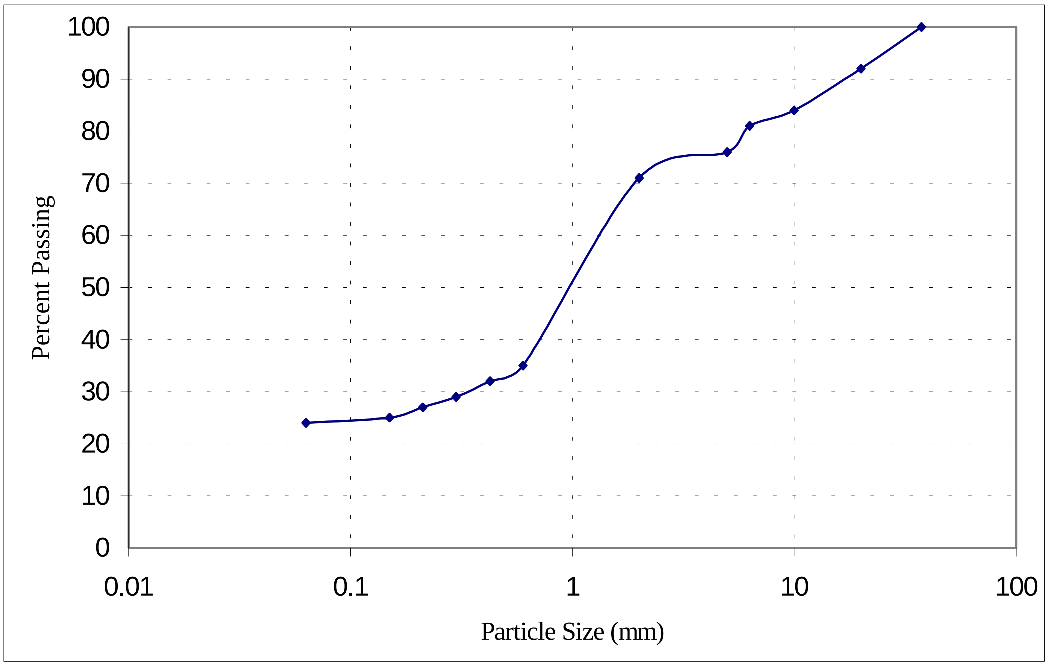
Previous research on synthetic fibres at the University of Birmingham has shown that 12 mm is most probably the optimum length of fibre which can be used to reinforce a clayey soil. A laboratory investigation on Oxford Clay and sisal also indicates that 12 mm is possibly the best length of fibre for achieving good performance in terms of strength. Therefore fibre length of 12mm was adopted for this study. As all the fibres were hand cut with a machete the lengths achieved ranged between about 8 to 18 mm. These fibres ranged in diameter from 0.075 to 0.207 mm. The average diameter was 0.15 mm.

Fibre concentrations of zero to 1% were used to determine their effect on MDD and OMC. This relationship is shown in Figure 3-2. The results show that there is a decrease in dry density from 2.15 Mg/m^3 for zero fibre content to 2.06 Mg/m^3 at 1%. However, the rate of decrease is the least between 0.2 and 0.6% fibre concentration. The reason for this behaviour is not entirely clear. The OMC increases rapidly from 9.7 % for zero fibre content to 11.2% for 0.4%. Thereafter there is little no change in OMC. Based on this it seems that tests most suitable range for fibre concentration should be between 0.2 and 0.6% as over this range changes in MDD and OMC occur at a slower rate.

Unconfined compressive strength (UCS) and CBR were determined for the Laterite clay with fibre concentrations ranging from zero to 1.0%. These tests were conducted on unsoaked specimen. Results are shown in Figure 3-3. They show that maximum values of UCS and CBR occur at 0.2% fibre concentration. Beyond about 0.3% fibre content the values of UCS reduce below that of the neat Laterite. CBR values reduce to a near limiting value at beyond about 0.4% fibre content. This limiting value is however about 10% greater than that of the neat laterite.

The results of CBR and UCS determinations show a slightly different trend because of the different modes of failure for the two tests.

Figure 3-1 Particle Size Distribution of Laterite



3.4 Use of Lime and Cement

As noted in earlier section, part of the strength from fibre reinforcement is from the cohesion developed between the fibre and the clay particles. Cohesion is very sensitive to moisture content. It can be lost entirely at high moisture contents. Thus the possibility of using lime and cement was considered as soil modifiers and binders in order to make the bond between the clay particles and fibres less moisture sensitive.

Figure 3-2 Relationship of MDD, OMC and Fibre Content of Laterite

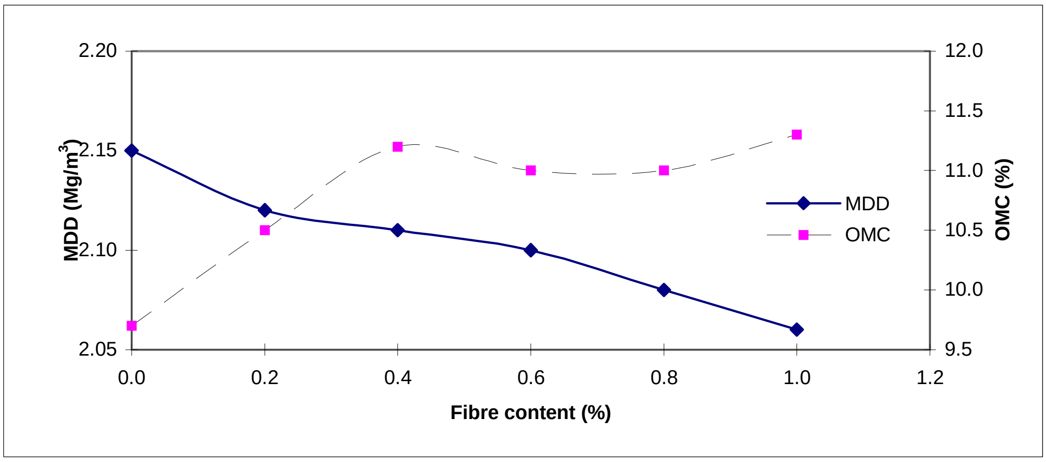
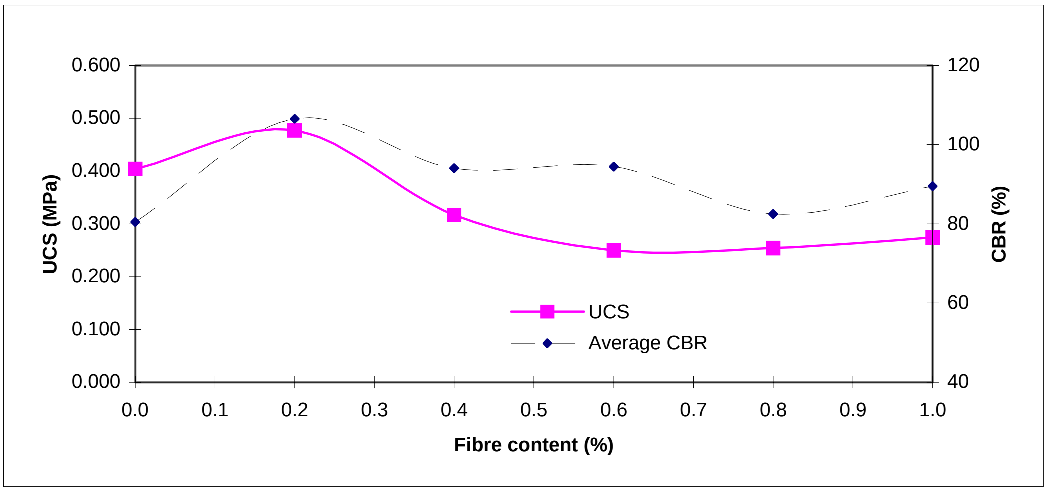


Figure 3-3 Relationship of UCS, CBR and Fibre Content for Unsoaked Specimen



3.4.1 Lime

Locally available hydrated lime (from Tororo, eastern Uganda) was used in this investigation. The available CaO content of this lime was about 45%. In terms of its particle size: 93% and 68% was finer than 425µm and 75µm respectively.

The ICL value of the Laterite using local lime was 3.6%. For this investigation 2, 4 and 6% lime was used for the laboratory study. Samples were prepared immediately after mixing lime with Laterite.

The relationship of lime, MDD, OMC and lime content is shown in Figure 3-4. There is near linear trend of decrease in MDD from 2.14 Mg/m^3 for zero percent lime to 2.06 Mg/m^3 for 6% lime. There is an increase in OMC from 10.9% for no lime content to about 12.6% for 6% lime. Beyond 4% lime change is gradual. These general trends are as expected and have been noted for other soils.

Lime was a preferred stabiliser for road construction in Uganda as it cost about one-third the price of cement.

3.4.2 Cement

Locally produced cement (Hodari Hima OPC Brand) complying with BS12 (1989 and 1991) was used in this investigation.

A very limited amount of work was done on cement stabilised soils due to limitations of time and funding; only 4% cement was considered. At 4% cement the MDD and OMC of the soil were 2.14 Mg/m^3 and 11% respectively; these values are similar to those of the virgin soil.

3.5 Fibre Reinforced and Lime and Cement Stabilised Laterite

As noted in Section 2.2 of this report, the rate of decrease in density is the least between 0.2 and 0.6% fibre concentration. Thus over this range the Laterite was least susceptible to change in fibre content.

For the planned field trials all the mixing was to be done manually. It was possible to obtain a homogeneous mix of fibres and soil for the laboratory trials. It was hoped to achieve the same in the field.

3.5.1 Fibre Reinforced Lime Stabilised Laterite

An investigation was conducted into the relationship of MDD, OMC and lime content when 0.4% fibre was added. Results are shown in Figure 3-5. Similar trends to those of lime stabilised Laterite were noted with no significant differences when compared to the unreinforced soil, see Figure 3-4.

Figure 3-4 Relationship of MDD, OMC and Lime Content

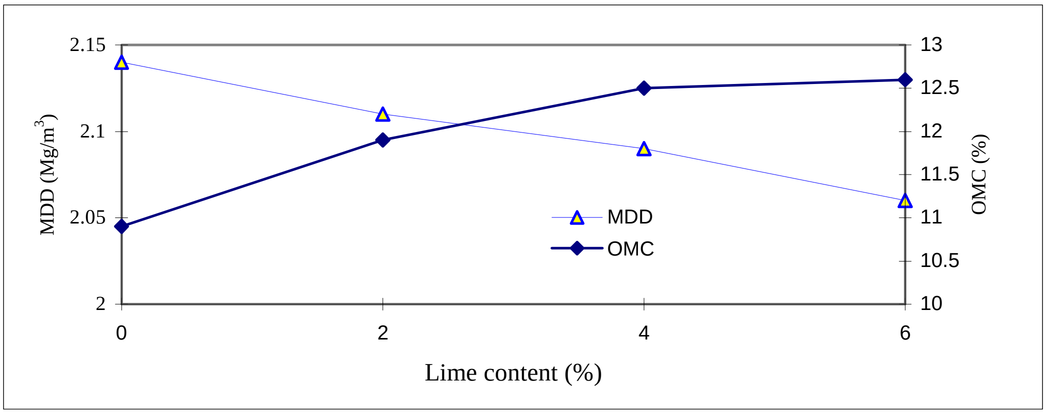
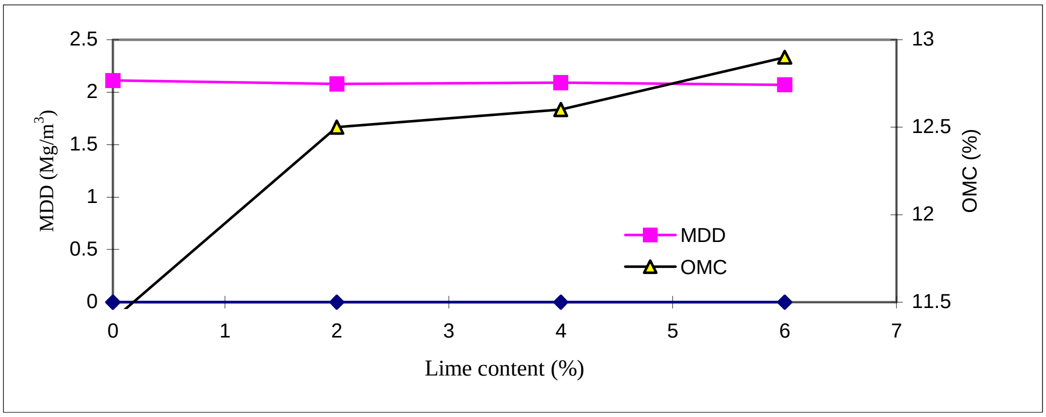


Figure 3-5 Relationship of MDD, OMC and Lime Content for 0.4% Sisal Fibre



Specimen were prepared for UCS tests at 95% MDD and at OMC. The UCS determinations at 7 days of curing and at 7 days of curing followed by 7 days of soaking are shown in Table 3-1. Results show that maximum unsoaked strengths were achieved at 4% lime cured for 7 days. With the addition of fibres maximum unsoaked strengths were achieved for Laterite with zero lime content. Addition of lime resulted in decrease in strength. When the specimen were soaked, those with zero percent lime collapsed within a day of soaking.

Samples with 0.4% fibre and 2% lime showed greater soaked strength compared to the specimen with the same fibre content and 4% lime. Thus 0.2% fibre content appears to be the optimum in terms of UCS. There was a general trend of increase in strain to failure when fibre was included.

Table 3-1 Results of UCS and CBR determinations for Lime and Cement Stabilised Laterite Reinforce4d with 0.4% Sisal Fibre

Sisal Content (%)	Lime Content (%)	Cement Content (%)	7 Day Curing		7 Day Curing plus 7 Day Soaking		
			Compressive Strength (MPa)	Strain at Failure (MPa)	Compressive Strength (MPa)	Strain at Failure (%)	CBR (%)
0	0	0	0.28	1.2	+		45
0.4	0	0	0.36	2.3	+		34
0	2	0	0.32	1.8	0.09	0.5	65
0.4	2	0	0.27	2.0	0.16	1.2	43
0	4	0	0.37	2.8	0.17	0.8	103
0.4	4	0	0.28	2.8	0.12	1.2	117
0	6	0	0.26	2.0			100
0.4	6	0					100
0	0	4	1.40	2.8	0.89	1.8	223
0.4	0	4	1.21	3.3	0.39	1.5	206

CBR determinations were also made on specimen cured for seven days and soaked for seven days. These results are also shown in Table 3-1. Maximum CBR value was achieved at 0.4% fibre content when 4% lime was included. Peak CBR of 117% was achieved. This about 14% greater than the value of lime treated soil only.

3.5.2 Fibre Reinforced Cement Stabilised Laterite

The UCS specimen were prepared at 95% MDD at OMC.

Inclusion of 0.4% sisal fibre resulted in a 14% decrease in the seven day UCS of unsoaked specimen to a value of 1.21 MPa. There was however, an increase in strain to failure when fibres were included.

There was also a reduction in soaked CBR values of 7.6% when fibres were included.

Possible explanations for this behaviour are that some of the cement reacts with the fibre or is neutralised by the fibre and is not available for the strength gain reaction or that too much fibre is added and it weakens the mixture instead of giving it additional strength.

Clearly further detailed investigation is required to eliminate the causes and determine the optimum mix design.

3.6 Conclusions

This tentative research has shown that it is possible to mix sisal fibres with Laterite to achieve a homogeneous mixture. At the limited number of concentrations of sisal examined 0.4% sisal with 4% lime gives the best performance in terms of soaked CBR.

Cement stabilised Laterite gave better performance in terms of soaked strength and CBR compared to fibre reinforced cement stabilised soil.

Further work is required to fully evaluate the potential of using sisal in construction of roads.

3.7 Field trials on lime stabilised fibre reinforced Laterite

3.7.1 Trial Section

A field trail was conducted on a section of an unsurfaced gravel road (Kasa Rifle Range Road) located about 10 km south east of Kampla. This particular section of road was selected because it had a uniform gradient and adequate amount of materials was available to conduct the trial. At the trial section the road was approximately 4 m wide. It has a gradient of about 1 in 70. A typical cross section is shown in Figure 3-6. Section of road prior to treatment is shown in Photograph 3-1.

Photograph 3-1 Section of Road Prior to Treatment

3.7.2 Construction

The trial section consisted of the following constructions.

Construction

Laterite (conventional construction)

Laterite and 4% lime

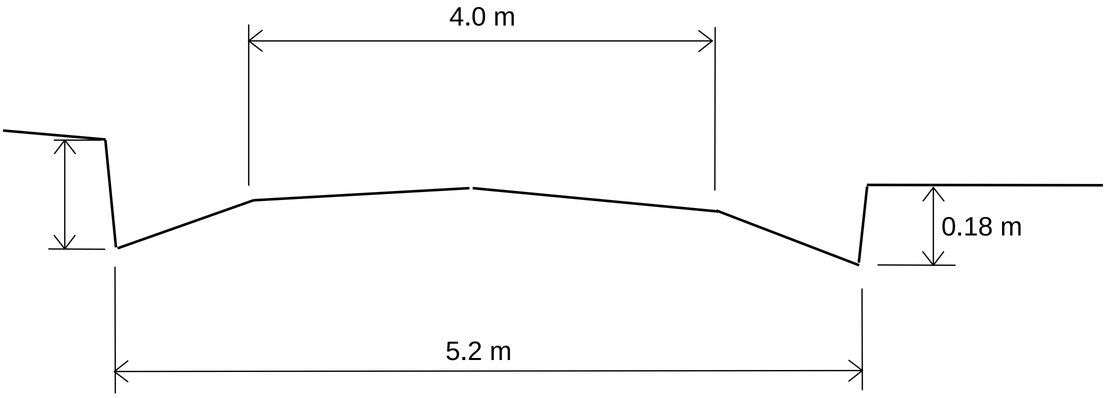
Laterite with 4% lime and 0.2% sisal fibre

Laterite and 0.4% sisal fibre

Each section was 10 m long and 4m wide. It was compacted to about 95% MDD.

The main trial section was constructed with 4% lime and 0.2% fibre. This was because in the main the method of cutting fibres was too slow and the required amount of fibre would have taken another week to cut. With the limited resources it was decided to proceed with 0.2 % fibre rather then the planned amount of 0.4%.

Figure 3-6 Typical Cross-Section of the Trial Section



Density determinations were made at the end of construction to ensure that the required compaction was achieved.

All the digging and mixing was conducted manually. A one tonne roller was used to compact the soil. The existing road surface was dug by hand as shown Photograph 3-2.

Photograph 3-2 Method of Excavation

In order to prevent carbonation of lime an approximately 12 mm thick layer of sacrificial Laterite was compacted on all the sections that contained lime.

The completed gravel road section is shown in Photograph 3-3.

Photograph 3-3 Completed Control Section Comprising Laterite Only

For the fibre reinforced and lime stabilised section, half the road width was constructed at a time. Lime was added manually as shown in Photograph 3-4.. Subsequent to this fibre was added (at 0.2 % concentration). Both the fibre and lime were mixed manually as shown in Photograph 3-5. The finished road section before application of the sacrificial layer is shown in Photograph 3-6 and the completed half section is shown in Photograph 3-7.

During the construction the main problem encountered was in mixing the fibres manually. It was not possible to mix fibres satisfactorily. Much effort was exercised in obtaining a garden rotivator, but none was available in Uganda. Further development work is required for mixing fibres and soil using a low technology techniques.

Photograph 3-4 Mixing Fibres and Lime

Photograph 3-5 Methods of Adding Lime

Photograph 3-6 Compaction

Photograph 3-7 Application of Sacrificial Layer

3.7.3 Monitoring was Conducted Over a Three Month Period at Decreasing Frequency.

The field trial was conducted towards the end of this study and therefore monitoring could only be undertaken for about three months. Within a few days of construction the section of road constructed with Laterite only showed extensive cracking. There was little evidence of cracking in the lime stabilised or the fibre reinforced sections.

Strength of subgrade was ascertained by undertaking in-situ CBR tests. All the CBR tests results are shown in Table 3-2. The results show that the required degree of compaction (95% of MDD or greater) was achieved for the Laterite, lime stabilised and fibre reinforced sections only. Section which was reinforced with sisal and stabilised with lime was compacted to only about 90 % MDD. It was found impossible to apply greater degree of compaction with the available plant.

Consequently the main trial section shows poorer performance compared to the others up to about 28 days. Thereafter the performance of all the sections is similar. It is conjectured that if adequate compaction was applied to the main trial section it would have exhibited much improved performance.

3.8 Conclusions

This was a pilot investigation into the use of fibre reinforced stabilised clayey soil. The following tentative conclusions are drawn for the field trial.

Although it was possible to mix fibre with soil to give a homogeneous mix in a laboratory it proved very difficult to do this in the filed. Small rotivator would have been more suitable but it was not available.

Due to the limitations of plant it was not possible to apply the required degree of compaction to the fibre reinforced lime stabilised section. However, in the long term it performed as well as the control sections.

The results of the trial therefore suggested it may be possible to get enhancement of engineering properties of Laterite for road construction. Further work is required to prove this.

It is necessary to develop low technology mixing and compaction plant.

3.9 Recommendations

Through a very limited laboratory and field trial this study has shown that reinforcement of Laterite with sisal fibres may have a beneficial effect on engineering properties. A further detailed investigation is clearly required to explore this area more fully. It is also recommended that other natural fibres are investigated for soil reinforcement. The above recommended research should lead to evaluation of the whole life cost of repairs.

This research has also shown that it is not always possible to translate laboratory techniques to field application. Thus it is also suggested that low cost equipment be developed for cutting sisal fibres and mixing them with soil.

3.10 Pothole trials

Pothole backfill trials were conducted on a surfaced main road in Kampala in Uganda. All the holes were located near the centre of the road as shown in Photograph 3-8.

Four materials were used to fill the potholes:

Pothole A	Laterite
Pothole B	Laterite and 0.4% sisal fibre
Pothole C	Laterite and 4% cement
Pothole D	Laterite plus 4% cement and 0.4% sisal fibre

Photograph 3-8 Completed Trial Section Comprising Lime and Fibres

In each case two sets of potholes were backfilled with the same material. Backfill was to a depth of approximately 100 mm. Backfill was considered to be compacted to 95% MDD. No quality control data was available.

Potholes ranged in size from about 300 mm square to 600 mm square. In most cases one small and one large pothole was backfilled with the same material.

After backfilling the potholes were not surfaced.

3.11 Observations

Within one week of backfilling all the cement filled backfill (from pothole C) was lost due to action of traffic. This pothole had to be backfilled again. Of the remaining over the following week pothole A showed about 40 mm of settlement (or loss of material) and pot holes B and D approximately 20 and zero mm settlement (or loss of material) respectively. During this period the weather was dry. Thus the fibre reinforced cement stabilised backfill performed the best.

At the start of week three there were very heavy showers. Within a day of this almost all the fibre reinforced material was lost. The fibre reinforced cement stabilised material also showed loss of up to about 30 mm of backfill. Some further material loss had occurred in the pothole filled with Laterite only. The possible reason for the loss of material with fibre reinforced is that it may not have been compacted adequately and that fibres may have provided pathways for water to migrate into the soil. This water would have resulted in a decrease in effective strength of soil under traffic loading resulting in failure. Thus, if fibre reinforced soil can be compacted adequately and the surface is sealed it may perform satisfactorily.

It seems that CBR may not be a good measure of the suitability of pothole backfill. As a pothole is subjected to dynamic loading it may be possible to use a Clegg Hammer type of device which subjects soil to an impact load. More works needs to be done in this area.

3.12 Conclusions

Potholes repairs conducted with fibre reinforced and cement stabilised Laterite performed the best in the dry weather. Penetration of water can result in loss of strength and hence failure of backfill.

CBR may not be a suitable measure for suitability of pothole backfill.

3.13 Recommendations

This research has shown that it may be possible to backfill potholes in surfaced roads with fibre reinforced cement stabilised soil. At 4% cement concentration surface may need to be sealed to gain satisfactory performance.

Further research is needed to evaluate variables such as fibre and cement concentrations. More research is also needed to develop a simple, and a more suitable test for evaluating pothole backfill.

Table 3-2 Monitoring Test Results for Field Trial on Reinforced, Stabilised, and Stabilised and Reinforced Laterite

Road Section	Laboratory compaction		Field density			CBR % at				
	MDD (Mg/m^3)	OMC (%)	Dry density (Mg/m^3)	Moisture content (%)	Degree of compaction (%)	7 days	14 days	28 days	56 days	84 days
Unstabilised Laterire	1.85	14.1	1.77 1.75	10.6 10.0	96 95	45 45 (45)	24 66 (45)	35 52 (43)	37 34 (35.5)	34 45 (37.5)
4% Lime Stabilised Laterire	1.82	15.9	1.74 1.73	8.7 10.3	96 95	26 45 (37.5)	52 30 (41)	40 53 (46.5)	43 61 (52)	42 45 (43.5)
4% Lime + 0.2% Sisal Stabilized Reinforced Laterire	1.84+	15.0+	1.59 1.57	10.3 10.6	91 90	35 30 (32.5)	28 36 (32)	41 34 (37.5)	40 50 (45)	42 43 (42.5)
0.2% Sisal Reinforced Laterite	1.93+	13.2+	1.68 1.76	7.5 7.8	94 99	23* 55 (39)	37 49 (43)	31 32 (31.5)	47 51 (49)	36 48 (42)

* Test point was not representative. The low CBR value is possibly due to the possible presence of a void

\+ Compaction tests are being repeated to verify the results.

( ) Indicate average CBR values

REFERENCES

Al Wahab, R.M. and Al-Qurna, H.H. (1955) "Fibre reinforced cohesive soils and application in compacted earth structures", Proceedings of Geosynthetics '95, IFAI, Tennessee, USA, Vol. 2, pp. 433-446.

British Standard Institution, BS1377:1990, Laboratory testing of Soils.

Flecher, C.S. and Humphries, W.K. (1991) "California bearing ratio improvement of remolded soils by the addition of Polypropylene Fibre reinforcement", Proceeding of Seventieth Annual Meeting, Transportation research Board, Washington, DC, USA, pp. 80-86.

Fretaig, D.R. (1986) "Soil randomly reinforced with Fibres", Journal of Geotechnical Engineering, ASCE, Vol. 112, No. 8, pp. 823-826.

Frempong, E. M. (1995) "A comparative assessment of sand and lime stabilisation of residual micaceous compressible soils for road construction", Geotechnical and Geological Engineering, Vol. 13 No.4 pp. 181-198

Gray, D.H. and Ohashi, H. (1983) "Mechanics of Fibre reinforcement in sand", Journal of Geotechnical Engineering, ASCE, Vol. 108, No. 3, pp. 335-353.