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THE UNIVERSITY OF BIRMINGHAM
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Report VI
Case Studies of Soil Stabilisation

DFID Department for International Development

February 2000

Appropriate and Efficient Maintenance of Low Cost Rural Roads

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Case Studies of Soil Stabilisation

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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/

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 Mr Matthew Brough, also of the University of Birmingham, who undertook the laboratory investigation and helped with the preparation of the report.

The author is grateful to Mr Tony Greening of Transport Research Laboratory, 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:

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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.

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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.

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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

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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: sulphonated 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.

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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.

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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 VI - CASE STUDIES OF SOIL STABILISATION

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REPORT VI - CASE STUDIES OF SOIL STABILISATION

1. INTRODUCTION TO CASE STUDIES

This part of the report contains two case studies regarding stabilisation of soils for road construction. Both the case studies deal with failure of stabilised soil.

The first case study is about a field trial using UBIX 10, an enzyme based stabiliser. The trial site was located along a mountain road in Nepal. The trial was conducted in mid-summer. However, soon after completion of the trial, the treated section had to be closed for repairs. The main reasons for lack of durability are considered to poor construction methodology and possibly unsuitability of the stabiliser for the soils encountered in the trial section.

During this investigation the supplier of UBIX 10 and was contacted and his views were sought. His response is awaited.

The second case study is about a road trial in Seychelles. In this case a section of road was stabilised with Terra-Fix, an acrylic resin based stabiliser. A year or so after completion of the road it developed pot holes. This investigation was conducted to evaluate possible reasons for development of potholes. Very limited information was available from the trials and only a small amount of sample was available for further evaluation. The main reason for failure is considered to poor mixing of stabiliser with soil during construction. Although much effort was expended in contacting the supplier of Terra-Fix no contact was established.

The two studies have highlighted problems with design and construction of stabilisation and the need to keep good records to help identify cause(s) of failure.

The two studies are described separately. In case conclusions are drawn and recommendations are made.

2. CASE STUDY 1 – STABILISATION OF A MOUNTAIN ROAD IN NEPAL

2.1 Introduction

A section of unsealed rural road located in mountainous area of Nepal was stabilised with an enzyme stabiliser. Within a few months of completion of construction the road became heavily rutted and was closed for repairs. This report deals with the design and construction of this road and identifies possible causes for lack of durability.

Both the stabiliser and the sections of the road for the trial were chosen by the contractor with no consultation with the University of Birmingham.

2.2 Background

During the last two decades, the road network in Nepal has expanded rapidly with a notable increase in demand for an improved transport network in the rural 'hill' areas. However, construction of roads is often impeded by lack of financial resources and limited availability of good quality materials. This is compounded in the foothill regions by intensely variable weather conditions, excessively steep side slopes, and soil erosion. These problems have led to the rapid deterioration of 'new' unsealed gravel roads. Therefore, there is an urgent need to develop methods of constructing unsealed gravel roads, with locally available materials, that exhibit improved service life and require reduced maintenance.

Soils encountered in foothills are generally of poor quality for road construction. They are often uniform or gap graded granular soils. Suitable construction materials from borrow pits or from lower parts of the foothills often have to be moved to upper areas for road construction. Transport of these materials is invariably prohibitively expensive.

For this project enzyme based stabiliser, UBIX 10 was considered. Enzyme stabilisers can decrease water absorption and increase the cohesion of the soil matrix by forming a 'bio-cement'. Thus enabling marginal soils to be used in road construction.

M. K. Nirman Sewa, a local contractor, carried out the assessment of the original soil conditions and the trial. The design and construction of the trial was supervised by a consultant representing the supplier of the stabiliser (Anderson Affiliates Inc. (of Texas, USA)) and the contractor. A research associate from the University of Birmingham supervised both the initial laboratory and In-situ testing and was present at the trial as an impartial observer for the construction of stabilised road. He also undertook some post-construction testing. The interpretation of the test results was made by the contractor and the stabiliser manufacturer's representative.

No information was available about the design and construction of the road section that was stabilised.

2.3 Location

Stabilisation trials were performed on the Hile to Basantapur road in the foothills of the Himalayas in Eastern Nepal, 20 km north of Dhankuta. Dhankuta is the centre of all existing trade routes in the Eastern Zone of Nepal. Hence the surrounding infrastructure is of the utmost importance. The region has a sub-tropical monsoon climate and maximum relief of 2500 m. Regional geology consists of highly sheared low-grade metamorphic rocks generally covered by transported granular soils. During the monsoon season (typically June and July), with an average monthly rainfall of 712 mm and 549 mm respectively, erosion and occurrence of landslides are widespread (Cross, 1982). Possible trial sections were chosen based upon problem areas previously identified in the monsoon, when the road became too weak to support traffic. No quantitative information was available to prove this.

The site was located on the Hile to Basantapur Road in the Eastern Tarai of Nepal along the Koshi Highway (H08). Four sections of the road ranging in length from 170 to 300 m were made available for the stabilisation trial. The site was at an elevation of 2260 to 2410 m above the Universal datum. Approximate road traffic was 100 vehicles per day.

2.4 Objectives of the Research

Objectives of the study are listed below:

i. To assess the materials in the trial sections of the road and the borrow pits prior to stabilisation.

ii. To monitor quality control procedures followed during the stabilisation trials.

iii. To design and supervise post construction testing so that the performance of UBIX 10 stabilised sections could be evaluated.

2.5 Assessment of the Trial Sections

2.5.1 General Observations about the Existing Road Surface

The following general observations were made about all the sections investigated:

i. The trial sections comprised an earth road which seemed to be well compacted and there was no gravel-wearing course. Road surface showed severe pot holing, corrugations and rutting. There was no visible crown on the road.

ii. The base material consisted of a poorly graded soil with a high proportion of large cobbles (up to 200 mm in size). This was overlain with a thin layer of fines, which resulted in excessive dust even with the passage of slow moving vehicles. Much of the gravel exposed at the surface (20-50 mm) appeared to have been dislocated by the action of traffic. As much of the base coarse aggregate material was taken from the nearby river basin, quality control of imported aggregates was an important issue. The imported material was not considered to be strong enough for use in gravel roads as some of it could be crumbled by hand.

iii. The fines from the road had high visible mica content.

2.5.2 General Observations about the Borrow Pits

Borrow pits positioned along each road section could be used for any additional material for the stabilisation trials. Borrow pit material seemed to contain much higher fines content than the existing road. The former also contained lesser quantity of cobbles compared to the road.

2.5.3 UBIX 10 Stabiliser

UBIX 10 is a biodegradable enzyme based stabiliser. It is non-hazardous to man, flora, fauna and aquatic life.

Whilst it is possible to use UBIX 10 for poor quality soils, they must possess two distinct characteristics: the soil must contain some clay and must be well graded in terms of its particle size distribution.

UBIX 10 is mixed with salt free water before application to soil. On average, one gallon (US) of UBIX 10 diluted with an appropriate amount of water can be used to treat 115 m^3 of soil.

The suggested application rates are:

Clayey soil - 0.033 l/m^3 UBIX and 0.00297 l/m^3 binder

Sandy soil - 0.035 l/m^3 UBIX and 0.00318 l/m^3 binder

Detailed information about the UBIX 10 stabiliser and the binder is given in APPENDIX I.

2.6 Pre-stabilisation Testing

2.6.1 Method of Sampling

Typical depth of stabilisation with UBIX 10 is between 150 to 200 mm. Sampling was therefore confined to a depth of 200 mm below the surface. Samples were taken from near the left, centre line and right sides of the road positions and sealed in plastic bags. All aggregates greater than 75 mm were removed from samples. Samples were also taken from borrow pits adjoining the trial sections of road. Sampling depth in borrow pits was not specified.

2.6.2 Testing Schedule

The following tests were conducted on the material from the existing road and the borrow pits.

- In-situ moisture content*
- Particle size distributions*
- Index tests – Liquid Limit and Plastic Limit*
- Compaction *
- In-situ density
- CBR – Soaked and unsoaked
- Cation exchange capacity
- Dynamic Cone Penetrometer
- Clegg Hammer

**Tests recommended by the manufacturer of UBIX 10*

2.7 Test Results and Discussion

2.7.1 In-situ Moisture Content

In-situ moisture contents of the existing road material were determined prior to construction. Results are summarised Table 2-1. These range between about 1.5 and 5.4%. It should be noted that the moisture contents determinations were made in the dry, summer season.

Table 2-1 Summary of In-situ Moisture Content Determinations for the Existing Road and Borrow Pit Materials

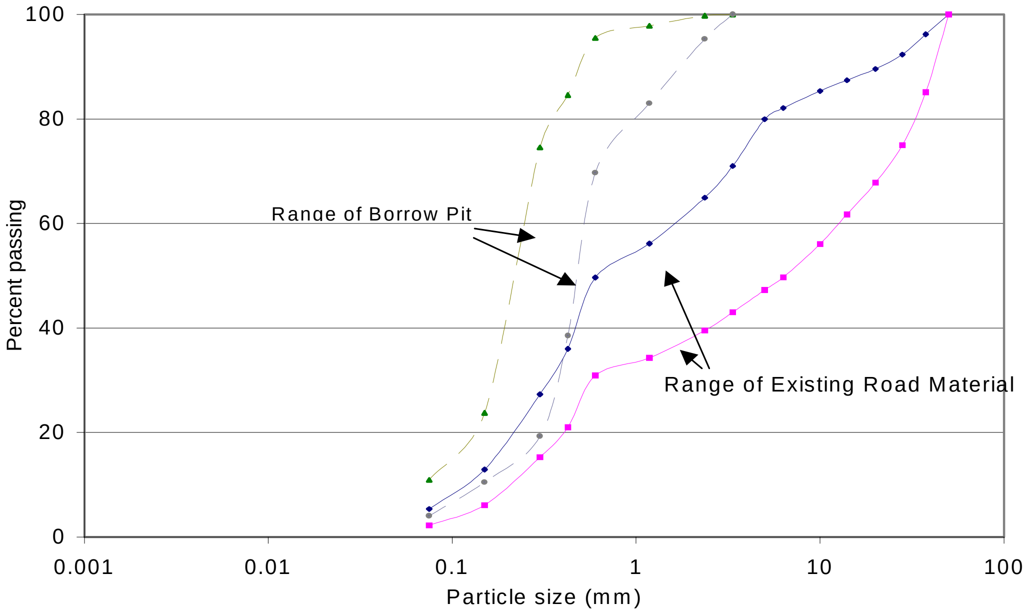
Location	In-situ Moisture Content (%)	
	Range	Average
Existing road	1.54 to 5.4	3.5
Borrow pits	2.9 to 5.28	4.11

2.7.2 Particle Size Distribution

Particle Size Distribution (PSD) tests were conducted in accordance with BS1377 (Part 2, 1990). The PSD envelopes for both the existing road and the materials are shown in Figure 2-1.

The borrow pit material comprised clayey/ silty fine to coarse sand. This sand was uniform with a Uniformity Index (Cu) of about 4.4. The existing road material was well-graded and comprised slightly clayey/silty fine sand to coarse gravel. It should be noted that particles larger than 75 mm were removed prior to the PSD analyses. The largest particles in the road surface were up to about 200 mm in size.

Figure 2-1 Particle Size Distribution of Material in Trial Sites and Borrow Pit



2.7.3 Index Test Results

Liquid limit was determined using the Casagrande apparatus. Plastic Limit was determined using the method stipulated in BS1377 (Part 2, 1990). Fifteen tests were conducted on samples from the existing road material and the borrow pit. Results show that all soils sampled were non-plastic with the exception of one area of the existing road, which exhibited slight plasticity.

2.7.4 Compaction Tests

All dry density and moisture content relationships were determined in accordance with the modified AASHTO test, using a 4.5 kg hammer. This procedure was used for all the laboratory compaction tests in Nepal. Compaction test results are summarised in Table 2-2.

The results show slightly lower maximum dry density and higher optimum moisture content for the borrow pit materials compared to the existing road. This reflects the differences in the particle size distribution for the two sites.

Table 2-2 Summary of Compaction Test Results for the Existing Road and Borrow Pit Materials

Location	Maximum Dry Density (Mg/m^3)		Optimum Moisture Content (%)	
	Range	Average	Range	Average
Existing road	1.818 to 2.140	2.039	7.4 to 11.9	9.5
Borrow pit	1.724 to 2.072	1.870	12 to 12.4	12.2

2.7.5 Cation Exchange Capacity

The Cation Exchange Capacity (CEC) was determined in accordance with the procedure described by Paige-Green et al. (1996). CEC was determined for both sections of the road to be stabilised and borrow pit material and results are summarised in Table 2-3 summarises the results.

Table 2-3 Summary of CEC Determinations for the Existing Road and Borrow Pit Materials

Location	Cation Exchange Capacity (meg/100g)	
	Range	Average
Existing road	1.1 to 2.4	1.7
Borrow pit	0.7 to 3.7	2.2

All the soils exhibited low CEC values of between 0.7 and 3.7 meq/100g of soil. Paige-Green et al., (1996) suggest that soils with a CEC of more than 15 meq/100g are suitable for treatment with stabilisers. The manufacturer of the stabiliser does not give guidance about the CEC values of soils that may be suitable.

2.7.6 In-situ Density

In-situ density could not be determined due to the presence of a high proportion of cobbles and boulders in the road surface.

2.7.7 CBR Tests

Due to a lack of sufficient number of moulds and time required to perform laboratory CBR tests, both soaked and unsoaked tests could not be performed. Therefore In-situ CBR values were estimated using a Dynamic Cone Penetrometer (DCP) and a Clegg Hammer.

DCP and Clegg Hammer measurements were made along the existing road prior to stabilisation. This enabled an assessment of In-situ CBR of the existing road prior to stabilisation. This was used to assess the effectiveness of stabilisation.

2.7.8 Dynamic Cone Penetrometer

A DCP was used for this investigation. DCP testing was performed at 50 m intervals along the road section to a depth of 800 mm. Results from left, centre line and right positions gave average values for the road section. Penetration rates as low as 0.5 mm/blow were acceptable. If there was no penetration after 20 consecutive blows the reading was discarded. For points with low penetration recorded, the test was repeated until sufficient penetration was obtained. Repeat tests were performed a minimum 300 mm away from the initial sampling point.

Several parameters were analysed using DCP results to 800 mm depth. DCP value to a depth of 800 mm (DN_{800}), equivalent CBR at depth (%) and the pavement strength Balance Number (BN) were be evaluated. The results of the DCP tests together with CBR values are summarised in Table 2-4.

The results show that up to an average of 74 and 57% of the structural strength of the road was provided by the top 100 and the top 200 mm of the pavement thickness respectively.

CBR values and pavement balance numbers suggested that the top 200 mm of the existing gravel road was relatively strong. CBR values were high enough to be considered to be sufficient for an unsealed gravel road. However, poor ride quality, loss of shape and dust considerations made it necessary to stabilise it. Furthermore, during the wet season it was envisaged that the pavement structure would lose considerable strength.

Table 2-4 Summary of DCP Test Results for the Existing Road

DCP Parameter	Road Position		
	Left	Centre line	Right
DN_{800}	7.2	10.0	12.4
BN_{100}	33	41	43
BN_{200}	54	66	58
$DN_{0\text{-}100}$ (CBR)	4.3 (64%)	3.2 (94%)	4.2 (66%)
$DN_{100\text{-}200}$ (CBR)	4.0 (70%)	10.7 (20%)	8.9 (26%)
$DN_{200\text{-}300}$ (CBR)	6.7(37%)	16.0 (12%)	16.1 (12%)

The DN_{800} is the rate of penetration of the DCP (mm/blow) to a depth of 800 mm.

A short note on converting DCP test results to CBR and determination of the BN is given in Appendix 3.

2.7.9 Clegg Hammer Test

The effective depth of material which can be assessed with a Clegg Hammer is between about 100 to 150 mm. It was therefore considered for evaluating the performance of stabilisation.

Average Clegg Hammer Impact Values (IV) for the left, centre line and right positions at various sections along the trial and control sites are given in Table 2-5.

The equivalent CBR values (calculated from IV) in the main are above 40% and have an average value of about 66% for the top 150 to 200 mm of the road structure. This correlates well with the CBR values estimated from the DCP tests which gave an average value of about 56%. It is to be emphasised that all the measurements were made during the dry season. It was envisaged that there would be a considerable loss in strength during the wet season.

Table 2-5 Average Clegg Hammer Impact Values (IV) for the Left, Centre Line and Right Positions for Existing Road

Section	Road Positions IV (CBR(%))		
	Left	Centre Line	Right
1	28 (55%)	34 (81%)	16 (18%)
2	33 (76%)	40 (112%)	25 (44%)
3	28 (55%)	35 (86%)	24 (40%)
4	27 (51%)	37 (96%)	38 (101%)
Average	29 (59%)	36 (91%)	26 (47%)

IV = Impact Value; Equivalent CBR (%) = 0.07(IV)2

2.8 Construction of the Trial Sections

UBIX 10 was used to stabilise two sections of the existing road:

- Trial A was 100 m in length, Trial B was 60 m in length.
- A 20 m long control section was also constructed.

2.8.1 Design

Due to the sandy nature of the soils encountered, stabiliser and binder concentrations of 0.035 $1/m^3$ and 0.00318 l/m^3 of soil respectively were used for all the trial sections. Road base depth of 15 cm was to be stabilised. Treated soils were to be compacted at 2% below OMC according to UBIX guidelines.

2.8.2 Trial A (100 m of UBIX 10 Stabilised Road Base)

The existing road was scarified. This took longer than anticipated due to a lack of teeth on the grader. Any oversize material (>200 mm) was removed by hand after scarification.

Water was brought up to the site in a 10,000 l capacity water truck. A 1,000 l capacity bowser was used to distributed water over the entire length of the trial section a day before the stabilisation.

Examination of the scarified road base suggested there was not enough material to obtain the required grade and depth of stabilisation. Therefore, borrow pit material (sourced from organic road side slopes) was distributed over the existing scarified road with the grader. A disc plough was used to mix the materials.

UBIX 10 and binder were added to the water bowser. The water bowser was moved backwards and forwards to thoroughly mix the solution. The rate of application of the stabiliser was difficult to control, as the discharge was gravity fed.

The grader formed the loosened soil into a windrow on one side of the road. UBIX solution was added to the road surface and the windrowed soil was folded back onto the UBIX saturated soil. This process was repeated until all the UBIX solution had been distributed. After this 1,000 l of water was added to the stabilised soil.

Additional water was required for compaction. However, this was not available as the water truck broke down on its way to the site. Therefore, the material was compacted before it became unworkable. Based on local experience it was envisaged that 12 passes of a ten tonne steel roller were required to achieve adequate compaction. However, only one pass was made before construction had to be stopped due to nightfall. The following day a final 'fog' coat of UBIX stabiliser was added to the compacted road surface using the water bowser.

2.8.3 Trial B (60 m of UBIX 10 Stabilised Road Base)

The construction procedure for this trial section was similar to that of Trial A. To increase the fines content a red clay available from road-side embankments was added to the scarified road surface. This red clay had not been tested.

For this trial section enough water was available to achieve OMC.

Initial compaction was made by up to four passes of the water truck. This was followed by at least eight passes of the steel-wheeled compactor.

Finally, two passes with the grader gave the compacted surface a smooth finish.

2.8.4 Control Section (20 m length)

This section was constructed in exactly the same way as Trial B, except that stabiliser was not added.

2.9 Post-Construction Monitoring

Post-construction monitoring was required to evaluate the effectiveness of stabilisation.

Moisture content determinations were made after mixing UBIX 10 and water with the soil. All the determinations were made immediately before compaction.

In-situ density, DCP and Clegg Hammer tests were carried out during the curing period of 24 to 72 hours after compaction.

2.9.1 In-situ density

2.9.1.1 Trial A

Average In-situ density of 1.76 Mg/m^3 was measured 24 hours after curing. This equated to about 86% of the MDD. The In-situ moisture was only about 1% below the required value. At the time of the construction it was known that these two parameters would be below the design values due to lack of compaction. However, the situation could not be remedied.

2.9.1.2 Trial B and Control Section

Both these sites received the same compactive effort. In-situ densities for both the sites gave values ranging from 1.7 to 1.81 Mg/m^3 equating to about 88 to 94% of the MDD. The In-situ moisture contents were about 1.3% and 2.6% above OMC for Trial B and the Control sites respectively.

2.9.2 DCP

The average results from both the stabilised trial sites (A and B) and the control section are presented in Table 2-6 in terms of CBR values measured after 24 and 72 hours of curing.

The results show that there was a small increase in CBR value in the uppermost layer from 24 to 72 hours for both the trials. For the 100 to 200 mm layer there was much greater increase in strength for Trial A compared to Trial B site where there was essentially no change in CBR. The deepest layer and the control sections, which were not stabilised, showed some improvements in CBR with time. It is possible the improvements were due to drying out. It is also possible that the range of observations is due to normal scatter in results, which would suggest that no improvement has taken place. The precise reason is difficult to identify.

Table 2-6 Average Results from both the Stabilised Trial (A and B) and the Control Section after 24 and 72 Hours of Curing

Depth (mm)	CBR (%)					
	Trial A		Trial B		Control	
	24 hours	72 hours	24 hours	72 hours	24 hours	72 hours
0 to 100	12	13	11	18	9	10
100 to 200	19	59	45	43	35	37
200 to 300	21	29	50	30	35	53

2.9.3 Clegg Hammer Measurements

For both the trial sites (A and B) there was time related change in CBR was determined from the Clegg Hammer tests. The improvements ranged between about 40 and 60 percent for the Trial sites A and B respectively. All the Clegg Hammer test results for the trial and the control sections after 24 and 72 hour of curing are summarised Table 2-7 in terms of CBR.

CBR determinations made using the Clegg Hammer suggest that there was time-related improvement in the stabilised sections. This test may be a better suited for ascertaining improvement since it measures a response from a larger area compared to the DCP (i.e. it has a larger "foot print"). Further work is required to ascertain the relationship between the DCP and the Clegg Hammer test.

Table 2-7 CBR Values (Calculated from Clegg Hammer Values) for the Stabilised Trial Sites and the Control Sections after 24 and 72 Hours of Curing

Strength	CBR (%)					
	Trial A		Trial B		Control	
	24 hours	72 hours	24 hours	72 hours	24 hours	72 hours
CBR (%)	17	24	19	31	15	14

2.10 Long Term Performance

All the trial sections were opened to traffic 72 hours after completion of stabilisation. Within 24 hours of opening ruts began to appear in Trial section B. Within about a month of completion, with the arrival of the monsoon season, the trial sections were closed to traffic for remedial work. Thus post construction monitoring was very limited.

2.11 General Discussion

UBIX 10 forms a "bio-cement" which relies upon the reaction between the enzymes in the stabiliser and the humic material in the soil. The resulting bonds lock the particles in place. Clearly a better distribution of particle sizes will result in higher strengths. Thus, considering the importance of the presence of the humic matter it is curious that the determination of organic content is not a requirement for stabilisation with UBIX 10. Although the UBIX 10 product information does state that the bacteria or the fungus and humus content of the materials to be stabilised should be determined. There is no guidance on the method of testing or how to interpret the results. Further guidance is required from the manufacturer of UBIX 10 stabiliser.

The UBIX consultant suggested two concentrations of UBIX 10: 0.033 l/m^3 UBIX and 0.00297 l/m^3 binder for clayey soils and 0.035 l/m^3 UBIX and 0.00318 l/m^3 binder for a sandy soil. For these trials the construction plant available was of poor quality and it was difficult to control the rates of application. The effect of variation of dose rate on the strength gain of soil is not known and it needs to be considered carefully. Guidance should thus be sought from the manufacturer.

The construction plant and its usage were clearly not adequate and will have no doubt affected the performance of the stabilised sections. This may have been the principle cause of poor performance of the road.

Soils at the trial sites contained a high quantity of mica (judged by visual observation). Mica is an inert material and its preponderance may have affected the stabilisation process. Laboratory based trial should have been conducted to ascertain the effectiveness of the stabiliser before conducting the field trial.

The contractor and the Department of Roads in Nepal fixed the location of the trial sites. All the initial test results were made available to the UBIX Consultant who designed the stabilisation scheme. It is therefore assumed that at the time he considered the results to be adequate for his design.

During the trial the contractor is known to have made promises to the Consultant regarding availability of plant and materials during construction. These did not always materialise (e.g. water at trial site A, although promised was not available in suitable quantity). This undoubtedly contributed to the lack of durability of the road.

2.12 Manufacturers Response

Subsequent to the preparation of the first draft of this report it was sent to Anderson Associates for comment. Their comments about the action of the UBIX binder are presented in Appendix II. All the factual changes they recommended about the report have been incorporated in the main text of the report.

It is very obvious from the comments received that UBIX stabiliser (Part I) and binder (Part II) should have been added to the soil separately. They were added to the water (and hence to the soil) at the same time for the trial. This was done by the consultant on site. Clearly manufacturers instructions were not followed. Since the binder has the effect of reducing the activity of the stabiliser and is a dust palliative. It is most probable that this was the key reason for the lack of performance of the stabilised road.

In view of the fact that the manufacturers instructions were not followed in detail and poor site facilities Anderson Associated have agreed to supply some UBIX 10 for a trial in Nepal.

In terms of the presence of humic material, it is suggested that there is adequate organic material present in all soils. In view of this it is still suggested that there should be some guidance in terms of upper limit of organic matter.

2.13 Conclusions

The following conclusions were drawn from this study.

i. The particle size distribution of the materials in the road and the borrow pits contained a small amount of fines. This may not have been adequate for UBIX 10 stabiliser to work effectively.

ii. Although the UBIX 10 product information suggests that the bacteria or the fungus and humus content of the materials to be stabilised should be determined. There was no guidance on the method of testing or how to interpret the results. Based on the assumption that all soils will contain some organic matter there should be an upper limit for the organic content.

iii. Some organic material from the roadside verges was added to the trial section A and B. It had not been tested prior to its use and its effectiveness is not known.

iv. CBR values determined using the DCP and the Clegg Hammer suggested that the existing road was strong enough. But these measurements were made in the dry season and it was envisaged that there would be a significant deterioration during the wet season. Furthermore ride quality was poor and the surface had many potholes.

v. The construction plant available for Trial A was not adequate and in particular inadequate amount of water was available at the site and insufficient compaction was applied to the stabilised section. Also the rate of application of the stabiliser was difficult to control, as the discharge was gravity fed.

vi. Post construction monitoring confirmed that compaction applied to all the trial and the control section was inadequate.

vii. DCP measurements showed that there was insignificant time-related improvement in strength for all the stabilised layers. The Clegg Hammer results however, suggested that there was some time-related improvement. Clegg Hammer test may be a better test for measuring the In-situ strength of the stabilised road. Further work is needed to evaluate the effectiveness of the DCP and the Clegg Hammer for stabilised soils.

viii. The trials was not a success as soon after completion of construction the stabilised sections began to rut and in the following monsoon theses sections of the road were closed for repairs. This lack of durability is considered to be in the main, due to poor quality of plant and construction techniques. It is also possible that that UBIX 10 may not have been entirely suitable for the soils encountered.

ix. Manufacturer's instructions on using UBIX 10 were not followed precisely for the trial. This is considered to be the most probable cause of the lack of performance the stabilised road.

2.14 Recommendations

Stabilisation trials are generally expensive to conduct as much work is required to investigate the properties of the materials and it is necessary to monitor them during and after construction for a prolonged duration. Whether a trail is a success or a failure, particularly the latter, the information gathered should be adequate to enable identification of causes of changes in behaviour.

The trial should be designed to take account of the type and quantity of the plant available and the expertise of the labour force to be used for construction and monitoring after completion of the works.

It is strongly recommended that all the aspects of the trial construction procedures should be kept as simple as possible.

It is also recommended that a laboratory trial should be conducted on the stabilised material prior to any full-scale field trials. This will enable a potential problem material to be identified before much time and money has been expended. For the laboratory study to be of value it should reflect the field condition such as temperature, humidity, rates of evaporation, etc. This area needs to be researched further.

In the case of these trials there were clear problems with the plant used for the construction works and its availability. There were also problems with the supply of water. It is therefore recommended that these trials be redone with more suitable quality control.

It is strongly recommended that every detail of manufacturer's instructions should be followed. It is also suggested that clarification should be sought about possible charges in procedure from the ideal prior to the start of the field trial.

3. CASE STUDY 2 – INVESTIGATION INTO FAILED SECTIONS OF ROAD STABILISED WITH TERRA-FIX AT PRASLIN IN THE SEYCHELLES

3.1 Introduction

Terra-fix, a synthetic stabiliser was used in the construction of bitumen sealed roads at two locations on the island of Praslin in the Seychelles. Subsequent to construction potholes appeared in the road surface. These trials were conducted in 1997. This report is about an investigation into possible causes of failure of these two trial sites.

The investigation was based on laboratory results obtained during and after construction. Post construction testing was conducted at the University of Birmingham on soil samples from the two sites and associated the borrow pit.

3.2 Aims of the investigation

The aims of the investigation were to identify the possible causes of road failure.

To achieve objectives it was necessary to review available site information (test results, monitoring records, etc.) and to undertake a laboratory investigation with the available samples.

3.3 Site Location

The islands of the Seychelles lie in the Western part of the Indian Ocean, north of Madagascar and 995 miles east of Mombassa, Kenya. They are located between latitude 4 and 5 degrees south of the equator at a longitude between 55 and 56 degrees east. Praslin is situated in the steeply mountainous Inner islands of the Seychelles, home to 97% of the total population of approximately 75,000.

Trial sites were located at Anse Kerlan and Anse Boudin sites. Borrow pit material was obtained from Anse Possession area.

The trial was conducted on a sealed section of the road but no information was available about its design and construction.

3.4 Terra-fix Stabiliser

Terra-fix, in its raw form, is a slightly alkaline liquid co-polymer acrylic emulsion with a 50% solids content. The solids content, based upon the chemical composition provided, consisted of resin solids and an emulsifier.

Resins typically waterproof soils but do not appreciably affect the angle of shearing resistance or cohesion of a soil (Road Research Laboratory, 1959). Although resin modified soils can be stock piled; it is usually desirable to compact them as soon as possible after mixing. Resins are also susceptible to microbial attack and therefore any waterproofing properties imparted may not be permanent. Literature suggested this durability may be even less under tropical climatic conditions (Road Research Laboratory, 1959).

Emulsions are generally only suitable for stabilisation in climates where rapid drying conditions occur. Therefore, emulsion based stabilisers were suited to the Seychelles climate. Emulsifiers should impart binding and water proofing properties to the stabilised soils.

Provided the stabiliser was applied correctly, with ‘good’ construction practices and quality control procedures followed, product guidelines suggested stabilisation should improve bearing capacity and water proofing characteristics.

Terra-fix, according to provisional product data, can be used for road maintenance, upgrades to black top and as a dust palliative in existing unpaved roads. It can also be applied in the construction of new roads. Product literature suggested Terra-fix could impart the following properties to soil and or gravel.

- It densifies the soil layer to which it is added by physically bonding the material
- It provides a hard load bearing aggregate, which is stable in water, after curing
- It densifies underlying, untreated layers
- It significantly reduces the rate of moisture evaporation from layer works
- It imparts anti-ravelling properties to base course layers, when used as a primer
- When used as a primer, terra-fix ‘armour-plates’ the base course surface preventing embedment of any aggregate contained in the wearing course

From the product literature it was not possible to glean any information about the soils for which Terra-fix was most suited. Despite extensive efforts to contact the manufacturer of the stabiliser no communication was established.

3.5 Construction Requirements

The following requirements were specified for the stabilised road base.

Minimum Thickness	150 mm
Maximum dry density	98%
Minimum compressive strength after 7 days curing	1700 N/mm^2

3.6 Stabilised Road Performance

Post construction, the stabilised road exhibited severe pot holing and corrugations as shown in Photograph 3-1. Potholes typically occur in gravel roads, which contain reactive fines that are susceptible to water. Therefore, it was possible that the stabiliser had not water proofed or encapsulated the fines adequately.

Photograph 3-1 Occurrence of Potholes and Corrugations

3.7 Laboratory Investigation

Laboratory tests were performed at the University of Birmingham, in the UK, to augment some of the field tests conducted in the Seychelles during construction. Although it was planned to undertake x-ray diffraction and some chemical tests to ascertain the action of the chemical on the clay it was felt that samples obtained were not representative enough. Thus, emphasis was directed towards simple mechanical tests.

3.8 Sampling

Only about 5 to 6 kg of soil was available from each site. Samples obtained from the various sites are given in Table 3-1.

Samples from the stabilised areas were undisturbed and were taken through the depth of the stabilised layer. All samples were stored in plastic film and were not tested immediately.

Therefore, some of their characteristics may have changed. Before testing all samples were classified visually, air dried and stored in airtight containers.

Table 3-1 List of Samples Available for Examination in the UK.

Site	Sample Description	Sample Dry Weight after Air Drying
Anse Kerlan	Terrafix Stabilised Road	6.348 kg
Anse Boudin	Terrafix Stabilised Road	6.615 kg
Anse Possession	Weathered Granite Borrow Pit	5.031 kg

3.8.1 Tests Undertaken in the UK

Tests undertaken at the University are listed below.

- Particle Size Distribution
- Plasticity
- Cation exchange capacity
- Organic content
- pH
- Diertert compaction

These together with the relevant standard are given in Table 3-2 and Table 3-3 for the Anse sites and the Borrow pit material respectively.

Table 3-2 Tests Undertaken in the UK on the Materials from the Anse Kerlan and Anse Boudin Sites (stabilised material)

Test Type	No.of Samples	Standard	Amount of Material Used	Description of Material Used	Soil Condition as Tested
Visual assessment	1 per site	-	all material	all material	as received
Plasticity	2 per site	BS 1377 (1990) and ASTM D421	1000 g	passing 425 µm sieve	air dried
Cation exchange capacity	3 per site	Paige Greene, P., Coetser, K., (1996),	180 g	passing 425 µm sieve	air dried
Organic content	3 per site	CNAL (1995) Procedure S1810	300 g	passing 425 µm sieve	air dried
pH	3 per site	CNAL (1995) Procedure S1820	300 g	passing 425 µm sieve	air dried
Density after stabilisation	4 per site	BS 1377 (1990)	4000 g	stabilised material	air dried

Table 3-3 Tests Undertaken in the UK on the Borrow Pit Material (unstabilised)

Test Type	No. of Samples	Standard	Amount of Material Used	Description of Material Used	Soil Condition as Tested
Visual Assessmen t	1	-	all material	all material	as received
Particle Size Distribution	1	BS1377 (1990)	5031 g	all material	air dried
Plasticity	2	BS 1377 (1990) and ASTM D421	500 g	passing 425 µm sieve	air dried
Cation exchange capacity	3	reference	90 g	passing 425 µm sieve	air dried
Organic content	3	CNAL (1995) Procedure S1810	150 g	passing 425 µm sieve	air dried
pH	3	CNAL (1995) Procedure S1820	150 g	passing 425 µm sieve	air dried
Diertert compaction	1	Head (1980)	1500 g	passing 2 mm sieve	air dried

3.8.2 Test Results Available From Seychelles

All the tests conducted in Seychelles for which results were available are listed below.

- Particle size distribution
- Plasticity
- Heavy Compaction test

The above tests, together with the relevant standard are given in Table 3-4, 3-5 and 3-6 for the unstabilised materials from Anse Kerlan, Anse Boudin and the Borrow pit respectively.

Table 3-4 Tests Conducted in Seychelles on the Anse Kerlan Material (unstabilised)

Test Type	No. of Samples	Standard	Description of Material Used	Soil Condition as Tested
Particle Size Distribution	1	not specified	all material	oven dried
Plasticity	2	not specified	passing 425 µm sieve	One sample oven dried and pestle, one as received
Heavy Compaction Test	1	BS 1377 (1975) Test 13	passing 20 mm sieve	oven dried

Table 3-5 Tests conducted in Seychelles on the Anse Boudin material (unstabilised)

Test Type	No. of Samples	Standard	Description of Material Used	Soil Condition as Tested
Plasticity	3	not specified	passing 425 µm sieve	1 oven dried and pestle, 2 as received

Table 3-6 Tests Conducted in Seychelles on the Borrow Pit Material (unstabilised)

Test Type	No. of Samples	Standard	Description of Material Used	Soil Condition as Tested
Particle Size Distribution	1	not specified	all material	oven dried
Plasticity	1	not specified	passing 425 µm sieve	oven dried and pestled
Heavy Compaction Test	1	BS 1377 (1975) Test 13	passing 20 mm sieve	oven dried

3.9 Test Results and Discussion

3.9.1 Sample Descriptions

No sample descriptions were available from the test data sheets from Praslin for the borrow pit material. In the UK this material was described as loose greyish-brown uniformly-graded very weakly-cemented sand-aggregates. Sufficient clay was present to impart some plasticity to the material.

The undisturbed stabilised soil was described as a red/grey gravely sand-sized material. The undisturbed soil samples from the Anse Kerlan and Anse Boudin area consisted of stabilised and unstabilised pockets throughout. This was indicated by sections of cemented and weakly cemented soil, suggesting non-uniform distribution of the stabiliser throughout the soil mass. The cemented sections were difficult to abrade and crush by hand, suggesting stabilisation had occurred in these areas. The specimen from Anse Kerlan showed greater amount of stabilised soil aggregates compared with the sample from Anse Boudin site.

3.9.2 Particle Size Distribution

Particle size distribution (PSD) of the borrow pit and the Anse Kerlan site materials were determined in the Seychelles. PSD of the Anse Boudin site soil was not determined in the Seychelles. Results indicated the borrow pit material was gap graded and comprised about 50% each of fine to medium sand and fine gravel. The test results on the borrow pit material in the UK suggested the material was well graded with a Uniformity Coefficient (Cu) of 10 and particle size ranging from fine sand to medium gravel. From the limited amount of data it seemed there was some variability of material in the borrow pit.

The soil from Anse Kerlan site was uniformly graded with a Cu of 4 and particles ranging in size from fine sand to fine gravel.

As the suppliers of Terra-fix, A.B.E Construction Products Inc., did not provide any guidelines regarding suitable soil types for stabilisation, comparisons were drawn from cement/chemical stabilisation methodologies. The PSD limits for suitable soils to be stabilised and the Praslin soil compliance are shown in Table 3-7.

The Seychelles and U.K. test results show that all of the soils were suitable for stabilisation.

The permeability of the Praslin soil was estimated from PSD results (using Hazen's formula). The PSD for all the soil samples were similar with an estimated permeability is 1.5-2.5 x 10^{-4} m/s. At this high permeability water would rapidly permeate through the road base.

Table 3-7 Comparison of Particle Size Distribution Limits of Praslin Soil with the Limits of Soil Suitable Soils for Cement Stabilisation.

Soil	>50% passing 3.35 mm sieve+	>15% passing 0.425 mm sieve+	<50% passing 0.075 mm sieve+	Maximum particle size of 75mm+	>15% passing 0.425 mm sieve*
Anse Kerlan soil (Seychelles results)	Yes	Yes	Yes	Yes	Yes
Borrow pit soil (Seychelles results)	Yes	Yes	Yes	Yes	Yes
Borrow pit soil (U.K. results)	Yes	Yes	Yes	Yes	Yes

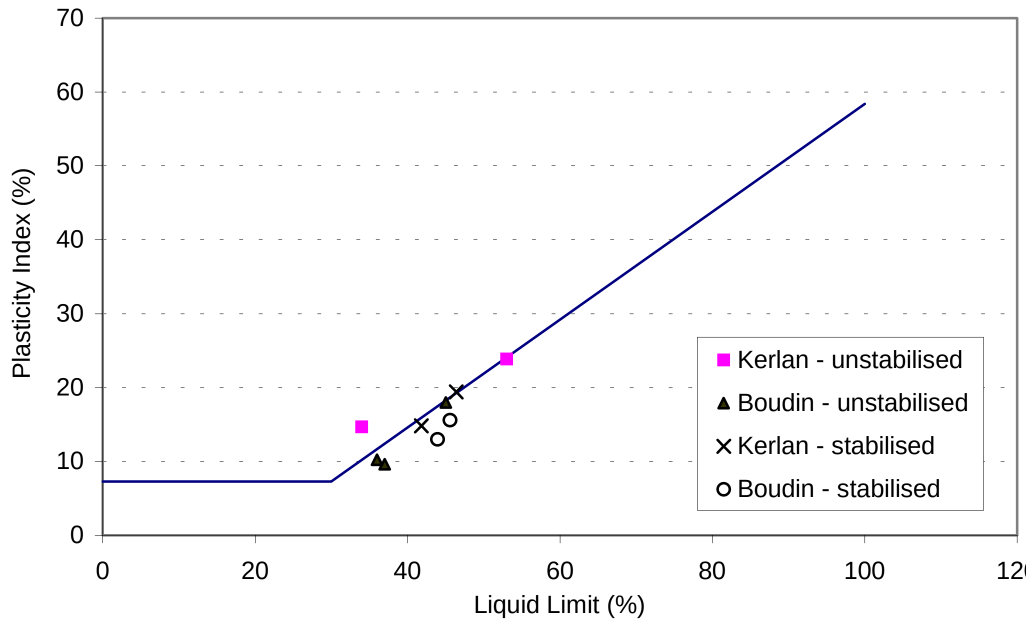
+ based upon advise of the Highway Research Board of America (1943) for suitability for cement stabilisation

** based upon advice from chemical stabiliser manufacturers for suitability for stabilisation*

3.9.3 Index Properties – Liquid Limit (LL) and Plasticity Index (PI)

All the available results of LL and PI are shown Figure 3-1. They indicate that the fine material from both the Anse sites were essentially clays and silts or slightly organic clays of intermediate plasticity. The addition of the stabiliser grouped the material into a small zone, but it still remained within the description given above. Thus the effect of Terra-fix was minimal.

Figure 3-1 Index Properties of Unstabilised and Stabilised Soils from Seychelles



Borrow pit material was essentially a low plasticity clay. Again the effect of Terra-fix on the clay fraction was minimal.

The clay content of the materials examined and the available results appeared to be less than about 2%. Therefore, this small clay fraction was not likely to have a significant effect on the behaviour of the whole soil mass.

3.9.4 Cation Exchange Capacity

Cation Exchange Capacity (CEC) results for the existing road material prior to or after stabilisation were not available from Seychelles. CEC tests were conducted on the borrow pit samples to estimate the CEC of the existing road material. Results are given in Table 3-8. The CEC values for the stabilised and the unstabilised materials range between about 8.4 to 14.1 meq/100g of clay. Although the results for unstabilised materials from the two Anse sites are not available it is conjectured that stabilisation did not have a significant effect on the properties of the soil.

Table 3-8 Cation Exchange Capacity of Praslin Soils

Soil	CEC (meq/100g) range of values	CEC (meq/100g) average
Borrow Pit Soil (unstabilised)	8.4 to 12.2	10.9
Anse Kerlan Soil (post-stabilisation)	13.5 to 14.1	13.7
Anse Boudin Soil (post-stabilisation)	10.3 to 11.6	10.9

It was anticipated that the addition of the stabiliser would reduce the CEC of the soil. most stabiliser manufacturers claim that chemical stabilisers reduce the ‘reactivity’ of fines in soils, with a corresponding reduction in plasticity and cation exchange capacity. It seemed that Terra-fix stabilisation did not reduce soil reactivity.

3.9.5 Volatile Organic Content

Results Volatile Organic Content (VOC) for the existing road material prior to stabilisation were not available. Therefore borrow pit samples were used to assess the VOC of the existing road material prior to stabilisation. VOC test results are given in Table 3-9. Results show that VOC was greater after stabilisation. This could indicate an increased soil volatile organic content due to stabilisation. The chemical composition of Terra-fix, should increase the volatile organic content. Terra-fix application rates were of the order of 0.1 to 0.3% by volume of the material to be stabilised; this does not account for all of the observed increase in the organic content. It was more likely that the observed increased organic content was due to differences in the materials tested.

The manufacturers of Terra-fix stabiliser have not provided any guidelines on the effects of organic content on the performance of the stabiliser. As a general rule, chemical stabiliser manufacturers specify that stabilisers should not be used in highly organic or peat soils. Physical characteristics of soils are not normally influenced until the organic content rises above 2 to 4%. Therefore, the organic content of the soils tested may have been high enough to affect the physical stabilisation processes in soil.

Table 3-9 Volatile Organic Content of Praslin Soils

Soil	VOC (%) Range of Values	VOC (%) Average
Borrow pit soil (unstabilised)	2.0 to 3.1%	2.6%
Anse Kerlan soil (post-stabilisation)	4.4 to 5.0%	4.8%
Anse Boudin soil (post-stabilisation)	4.5 to 5.6%	5.1%

3.9.6 pH

No pH results were available from Seychelles for any of the materials investigated. Results of pH determined in the UK are given in Table 3-10. High pH (i.e. alkalinity) is known to affect the water proofing properties of resinous stabilisers. Terra-fix contained both an emulsifier and a resin. Since the average pH of the soil examined was 7.6 (i.e.neutral) it was not likely to have had an effect on the stabilisation process.

Table 3-10 pH of Undisturbed Samples of Stabilised Material taken from Anse Kerlan and Anse Boudin

Site	pH of Unstabilised Soil	pH of Stabilised Soil
Borrow Pit Materials	7.6	-
Anse Kerlan	-	6.6
Anse Boudin	-	6.6

3.9.7 Compaction

The maximum dry density (MDD) of the material from Anse Kerlan, determined in the Seychelles, was slightly lower than was observed in the borrow pit but the OMC of the former was greater. This suggested a slightly higher clay content for the Anse Kerlan soil. No compaction test results were available for the Anse Boudin area from Seychelles.

U.K. Compaction tests could not be conducted on the materials available as the samples were too small. Thus no comparisons and assessments were made.

3.9.8 In-situ Density

In-situ density was determined of undisturbed samples of stabilised material taken from Anse Kerlan and Anse Boudin. Test results are given in Table 3-11.

Table 3-11 In-situ Density Determined of Undisturbed Samples of Stabilised Material taken from Anse Kerlan and Anse Boudin.

Site	Density of Stabilised Soil (Mg/m^3) - Range of Values	Density of Stabilised Soil (Mg/m^3) - Average
Anse Kerlan	1.78 to 2.05	1.91
Anse Boudin	1.84 to 2.16	1.97

The results show a considerable range of values for density. Since the method of determining density showed considerable repeatability, it was suggested that variation in results was almost entirely due to the inconsistent application of compactive effort or nonuniform mixing. Due to the lack of information about field densities it was impossible to state whether the densities achieved in the field satisfied the specifications.

3.10 Conclusions

No definitive conclusions can be drawn as the results available from the trial for unstabilised and stabilised soil were very, very limited. It was also impossible to make contact with the manufacturer or the supplier of the Terra-fix stabiliser. Since a very limited amount of samples were available for examination at Birmingham University the conclusions drawn were best be tentative. These tentative conclusions are given below.

Results of index, particle size distribution, cation exchange capacity and volatile organic content tests showed some variation in the fines content of the soils. However, as the fines content (less than 60 μm) was less than about 3%, it was not likely to have a significant effect on the behaviour of the soil mass.

The main reason for localised failure was thought to be due to an inadequate mixing of Terra-fix with the host soil. This was concluded from the occurrence of the stabilised and unstabilised soil aggregates in samples of stabilised soil from both sites.

3.11 Recommendations

Although the use of chemical stabilisers is claimed to be cost effective their effect on soils, in particular the long-term effect, is not fully understood. There was little original information available for this investigation. Therefore the task of finding the causes of post construction failure was almost impossible.

The following recommendations are made regarding field trails.

- Adequate information should be gathered for the initial trials. This should include a detailed description of the soil pre and post stabilisation.
- All the original information regarding the stabilised and unstabilised materials should be saved for at least the desired life span of the construction.
- Monitoring should be conducted at regular intervals for a predetermined period and records should be saved for at least the design life of the construction.

With the above information in the event of a failure of the construction it should thus be possible identify the causes. Adequate quality control procedures should be in place to ensure adequate mixing and subsequent compaction. These should be standard requirements in any gravel road construction.

REFERENCES

BS1377 (1990), 'British standard methods of test for soils for civil engineering purposes - Part 2 classification tests', British Standards Institution, London.

Cross, W.K., (1982), 'Location and design of the Dharan-Dhankuta low cost road in eastern Nepal', Proc. Instn. Civ. Engrs., Part 1, 72, Feb., pp.27-46.

Paige Greene, P., Coetser, K., (1996), 'Towards successful SPP treatment of local materials for road building', South Africa DOT, research report RR 93/286.

TRRL (Information note), 'Operating instructions for the TRRL dynamic cone penetrometer', Transport and Road Research Laboratory, Overseas unit, Berkshire, U.K.

BS1377 (1975), 'British standard methods of test for soils for civil engineering purposes', British Standards Institution, London.

BS1377 (1990), 'British standard methods of test for soils for civil engineering purposes - Part 2 classification tests', British Standards Institution, London.

CNAL (1995a), 'Soil organic matter by loss on ignition', http://w4u.eexi.gr/~andreask /organicm/htm.

CNAL (1995b), 'pH in water', http://w4u.eexi.gr/~andreask/pH.htm.

Head (1980) Manual of soil laboratory testing, Volume 1: Soil Classification and Compaction Tests. 2nd Edition, Pentech Press

Highways Research Board of America (1943), ' Use of soil-cement mixtures for base courses', Wartime Road problems No.7.

Paige Greene, P., Coetser, K., (1996), 'Towards successful SPP treatment of local materials for road building', South Africa DOT, research report RR 93/286.

Road Research Laboratory (1959),'Soil mechanics for road engineers', HMSO, London.

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In association with
THE UNIVERSITY OF BIRMINGHAM
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THE UNIVERSITY OF NOTTINGHAM

Report VI - Appendix I
Case Studies of Soil Stabilisation

DFID Department for International Development

February 2000

Appropriate and Efficient Maintenance of Low Cost Rural Roads

Report VI - Appendix I
Case Studies of Soil Stabilisation

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/

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

REPORT VI - CASE STUDIES OF SOIL STABIILSATION

APPENDIX I - PRODUCT DATA SHEET
UBIX NO. 0010 SOIL COMPACTION AGENT

TABLE OF CONTENTS

TECHNICAL DETAILS
IMPLEMENTATION DETAILS

1. INTRODUCTION

UBIX No. 0010 Soil Compaction Agent is a synergistic mixture of enzymes, co-enzymes, binders, catalysts, wetting agents, surfactants, and water. Applied on site, it produces a compaction of 95% and above when applied to a well-prepared pulverised roadway bed.

UBIX Soil Compaction Agent contains no toxic substances or harsh chemicals. Its formulation is based on proprietary enzyme formulations manufactured from natural organic materials. The compounds produced are non-hazardous to personnel, animals, or aquatic life, non-corrosive, highly biodegradable, non-flammable, and incapable of autoignition.

Of great advantage is the fact that UBIX No. 0010, working effectively and efficiently, greatly reduces the time and cost normally required for construction of conventional roadways. Once the soil mass becomes thoroughly wetted with UBIX No. 0010 and water, it begins to react with the humus (bacteria) present in the soil. Consistently superior compaction occurs as dry layers within the compacted soil are eliminated.

As the reaction proceeds, a hydrogel condition develops to stabilise and to form a cementitious binder between the particles and grains of the soil that will develop substantial strength within one (1) to three (3) hours at temperatures between 50-90 F (9-29 C).

Ubix no. 0010 Soil Compaction Agent is used for:

- Construction Of Trafficable Roadways•
- Heliports
- Landing Strips
- Tennis Courts
- Parking Lots, Path & Cart Ways
- Pond Liner
- Adobe Brick
- Sub-Soil Stabilization Of Bldg Structures & Building Material Stockpiles

Ideally, the roadway bed will consist of a proper blend of different size aggregates, fines, soils, and clay so that when blended together with properly diluted UBIX No. 0010, all particles will pack together filling all natural voids to form a solid base.

When final compaction has been completed and the roadway allowed to cure the allotted time, all particles should be well packed and locked together, protected by a water-impervious very strong tight surface while the load-bearing capacity of the soil is greatly increased.

Because of the unique characteristics of this enzyme-based soil compaction agent, when the ideal conditions described above are not present, an application of UBIX No. 0010 on a well-pulverised roadway or pathway, utilising only locally available materials for construction, can result in a trafficable secondary roadway almost anywhere in the world.

This easy-to-apply product is especially appropriate for use at remote sites where supplies of road-building materials such as asphalt, tar, aggregate, fly ash, lime, and concrete are not locally available.

Roads will shed water, reduce dust, endure all kinds of weather conditions and limited maintenance.

UBIX No. 0010 makes it possible to build hard surface trafficable roadways in rural areas, forestry lands, and in under-developed countries, using only locally available natural materials and light construction equipment.

2. IMPLEMENTATION DETAILS

2.1 Quantity Determinations

For economy in transportation, UBIX No. 0010 Soil Compaction Agent is sold as a concentrate and must be mixed with water (clean or dirty) prior to use. Water activates the enzymes present. Where water is unavailable, the product can be shipped

ready mixed to the construction site without affecting the quality of the Compaction Agent. To determine the quantity of the UBIX/water compacting agent required, soil analysis and project dimensions (including depth, emergency lanes, and/or shoulders) are used. Soil analysis is used to determine:

- Quantity and type of sand present
- Quantity and types of various clays and silt
- Optimum moisture content of the soil

As an average, one gallon of UBIX No. 0010 is required for each 150 cubic yards of soil to be treated.

2.2 Project Proposals

Once soil properties have been investigated and the required quantity of material has been determined, should a client desire to use the engineering services proposed, a pricing proposal can be developed and submitted for client evaluation. Projects can be

priced by the kilometre or mile or any other unit of measure. In all cases, it will be in the best interest of the client to supply all construction equipment and on-site labour.

3. GEOTECHNICAL LABORATORY SOILS EVALUATION

3.1 Option 1

Prior to ordering UBIX No. 0010 Soil Compaction Agent, soils from the project site should be evaluated by a local geotechnical laboratory for the following soil properties. The results of this analysis along with the project dimensions (width, length, and base) should be forwarded to our Civil Engineer.

- Standard Proctor Density of the soil in pounds per cubic foot (kg/cm) and optimum moisture.
- In-place moisture (%)
- Liquid limit
- Plasticity index
- Sieve analysis

3.2 Option 2

A prospective client may collect twenty (20) pounds of representative soil from the first few inches (a depth of six-eight inches) of native soil at the project site and ship it to the Civil Engineer for performance of the soil analysis. Be sure to include the dimensions of the project. The cost for analysing the soil properties is $350.00.

3.3 Payment Of Engineering Fees

Whether either Option 1 or Option 2 is selected, the laboratory report on soil properties must be analysed by our Civil Engineer so that the quantity of UBIX No. 0010 purchased will not be larger than required or too small. The cost of analysing the report on soil properties is $75.00.

When Option 1 is selected, payment of the $75.00 analysis fee must accompany the soil report submitted. When Option 2 is selected, payment of the soil analysis cost of $350.00 and the fee for analysing the report of $75.00, a total of $425.00, should accompany the soil shipped.

4. UBIX NO. 0010 SOIL REACTION GUIDE WITH REGARD TO SOIL TYPE

4.1 Compaction of Clay Soils

In pure clays, because of the extremely fine grains involved, optimum moisture is relatively high, running from about 12-20%. In some instances, optimum moisture will run as high as almost 23%. The most difficult task is to attain a consistent homogenous mixture within the soil mixture. Where optimum moisture reaches toward 23%, it may be advisable to increase the catalyst-binder additive provided with the Soil Compaction Agent by about 10% as well as to add 10% sand to the clayey soil to neutralise the charge and to bring the soil back to a more "inert" condition. The additive is used to slow down premature drying ("shrinking") of the surface soil to avoid mud flat surface cracking.

Because UBIX No. 0010 has excellent qualities of penetration, the required homogenous consistency of clay material is more easily accomplished yet arrival at an optimum moisture content can be somewhat difficult. The soil may appear to be too wet before actually reaching optimum moisture content. If the optimum moisture content is exceeded, the material will cling to the mechanical equipment being used yet never reach the desired density.

UBIX No. 0010 provides an excellent example of its desirable qualities because clay is so difficult to work with. The grain sizes are small and the capillaries between the grains are also very small, so the curing period for the attainment of maximum cementation and sealing is usually longer. Clay will absorb lots of water very rapidly yet the surface may dry out before the layers below the surface have adequate time to cure. In order to reach the optimum state for enzyme compaction, sufficient time must be allowed for some evaporation of soil moisture before the cementing effect reaches its peak. The fine grain size and small capillaries in clay require longer periods for this to take place.

A curing time of at least sixty to seventy hours at mean temperature of 70 F (21 C) and humidity of 15% is recommended when compacting clay materials. The curing time is considered at a standard of a mean temperature of 70 F (21 C) and a humidity range of 15%.

4.2 Compaction of Sandy Materials

Sand in a clean, washed state represents the most difficult of soils to stabilise. Sand particles allow faster passage of free water in the soil. The retained surface tension of the water surrounding each particle is relatively low, and again, because of the grain size and shapes involved, such sands have little or no capacity for cementation without blending.

If a high degree of permanent density is required in clean sands under normal conditions, it becomes necessary to import fines (dirt and clay). By using UBIX No. 0010, the amount of import material is reduced considerably because the introduction of fine clays (about 10%) and silts will provide materials to fill the voids between the sand particles and provide a bonding action at a considerable higher rate than plain water. Bonding action in sandy soils can also be increased by a 10% addition in the amount of catalyst-binder utilised.

In sands or sands with fines, the optimum moisture will be higher than in finer grained soils. A ratio of 1 gallon of UBIX No. 0010 to 800-850 gallons of water may be employed if the fines do not exceed 10%. Curing time is reduced for sandy soils below that required for combination soils by about 40%.

4.3 Evaluation of Optimum Moisture

Begin the project by ascertaining optimum moisture. This is determined while soil is in the dry state. First, dry the soil as completely as is possible, weigh it, and then weigh the container in which the water is to be carried. Next, add the water to the soil. Start with about 5% by weight for silts, 12% for clays, and 7% for sand. The use of UBIX No. 0010 calls for a reduction by 1-2 points in the amount of water necessary to attain optimum moisture level.

Slowly add water and carry out these simple tests to get an approximate measure of the optimum moisture content. The test consists of placing a small amount of the set soil on a flat surface, rolling it into a string about inch in diameter. When the string maintains its shape, you have arrived at optimum moisture content. If the sample crumbles while you are rolling it, the moisture content is determined to be less than optimum. If it tends to flatten and become plastic, the moisture content is greater than optimum. When your tests indicate the correct amount of water has been added to the soil, weigh the remainder of the water and compare it with the total amount of water you had to begin with and you can then compute the correct percentage of water that needs to be used to obtain the optimum moisture content. If you encounter difficulty in doing this, contact a local geotechnical laboratory.

Other factors that affect the degree of optimum moisture are the relative humidity of the air and exposure to winds. In a condition of high humidity, it is best to stay below the true soil optimum. When there is a wind condition, particularly if it is hot and dry, you may need to add one or two percent additional moisture to prevent too rapid drying.

4.4 Determination of Moisture Content

Once optimum moisture level is determined, it is necessary to determine the actual moisture present in the soil in order to compute the proper amount of water needed to reach optimum moisture.

Weigh the material before and after drying and calculate the percent of loss. Knowing that a given amount of moisture is necessary for the area and knowing what mixture of enzyme you wish in relation to the total moisture, you can calculate the UBIX No. 0010 ratio to be mixed in the water for the application to the prepared roadway bed. The calculations must take into consideration the amount of water lost due to run-off which is the result of the water truck unloading at a faster rate than the soil can absorb.

It may be necessary to apply and mix thoroughly several times to reach the desired optimum. This mixing procedure is extremely important to ensure that no dry spots remain in the mixture at the time compaction is applied.

4.5 Compaction

Compact with a sheepsfoot roller or heavy rubber-tired vehicle. Be sure to compact to a density of over 100% of the corresponding maximum density obtained from laboratory Proctor tests.

4.6 Fogging after Compaction:

Twenty-four hours after compaction has been completed, a second application by a fog spray over the surface is highly desirable. This application prevents the development of surface cracks and alligatoring. It also adds to the cementing and sealing of the top layer from which the moisture with its UBIX No. 0010 additive may have been reduced because of the downward penetration to the lower layers. The surface of the compacted soil may also have been loosened due to the fracturing action in the soil caused by the mechanical compaction that has taken place.

4.7 Client Services

To avoid guesswork, the probability of purchasing too much or too little UBIX No. 0010 for a project and to better ensure successful application of UBIX No. 0010, clients are encouraged to obtain a geotechnical laboratory analysis of candidate soils as to the following soil characteristics and fax it to us for analysis. The fee for this service is $75.00 prepaid. If an order for UBIX No. 0010 is subsequently placed, the $75.00 analysis fee will be deducted from our invoice.

- Standard Proctor Density of the soil in pounds per cubic foot (kg/cm) and optimum moisture
- In-place moisture (9%)
- Liquid limit

- Plasticity index
- Sieve analysis

5. SPECIFICATION

5.1 Physical Data

Color: Brown/Black
In Dilution: Light Amber
Vocs: 0 Gr/Liter
Organic Solvents: None
Odor: Naturally Pleasant
Viscosity: Syrupy Liquid
Ph: 4.5 - 5.5
Solubility: Indefinitely Dispersible In Water
Flash Point: No Flash (Closed Cup)
Weight/Gal: 8.75 ± 0.2 Lbs/Gal
Boiling Point: 212 F (100 C)
Heat Stability: Up To 130 F (52.7 C)
Freeze/Thaw Stable: No Effect
Shelf Life: 24 Months

All ingredients are on the TSCA Chemical Substance Inventory. None are subject to any report or record-keeping requirements at this time. UBIX No. 0010 contains no citrus or pine oils to cause worker discomfort, allergic reactions, or headaches. No protective outerwear, goggles, face shields, or boots are required. UBIX No. 0010 is easily rinsed from washable clothing. Should a spill occur, simply flush away with water.

5.2 Non-Pollution Of Waterways

Testing under EPA 600/4089/001 entitled "Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms" showed no deleterious effect on aquatic life.

5.3 Biodegradability

When evaluated under EPA Regulation 40CFR 796.3260, UBIX No. 0010 was found to have a biodegradable level of 60% in 10 days and a 98.20% level in 26 days. This level represents a much higher level of biodegradability than the standard established as acceptable by most public-owned waste water treatment facilities.

5.4 Toxin Free

Independent laboratory tests have shown that UBIX No. 0010 will cause no Acute Dermal Toxicity, Primary Eye Irritation, Acute Oral Toxicity, or Primary Skin Irritation. All testing was conducted under the Federal Hazardous Substances Act under Consumer Product Safety Commission Guidelines in accordance with Good Laboratory Standard Practices as directed by the EPA. Copies of all test reports are available on request to qualified clients.

5.5 Application

Prior to beginning a roadway construction project, it is good engineering practice to obtain as much geotechnical information as possible pertaining to the materials available at the proposed construction site. Soil materials available at the construction site determine the water/UBIX dilution ratio most appropriate.

For economy in transportation, storage, and handling, UBIX No. 0010 is sold only as a concentrate. Under normal circumstances, the Soil Compaction Agent is mixed with water upon its arrival on site. However, if water is not readily available, UBIX No. 0010 can be pre-mixed with water and transported to the construction site in the ready-to-use condition.

UBIX No. 0010, a supply of water (clean or dirty), a spray bar applicator, motor grader, and a rubber-tired roller of some description, provide an efficient cost-effective method by which the densification of soil, sand or aggregate, uniformly mixed and moistened, is enhanced to achieve a compaction rate equal to or greater than 95%.

The admixture is delivered on site by a water truck, applied evenly by the spray bar, thoroughly and evenly blended by blading action into the prepared 6- or 8-inch-deep road bed base to assure an even mixture of UBIX/water and soil, then firmly compacted by a rubber-tired roller or by other means to the proper density and allowed to cure undisturbed for at least 72 hours, although it will develop hydrogel characteristics within 24 hours.

During grading, the road should be carefully crowned and shaped to allow proper drainage with ditches off each side of at least 24 inches below the lip of the roadbed for rain water run-off. The early developed hydrogel characteristics minimise the ability of moisture to penetrate and the swelling of any clay present. It reduces permeability and enhances unconfined compression strength. The treated roadbed will be highly resistant to water migration and to penetration within 30 minutes following compaction.

A successful project will depend on good construction practices, an optimum amount of moisture, the proper ratio of UBIX No. 0010 to the type of soil present, and professional roadway engineering expertise.

5.6 Cost-Effective

One drum (55 gallons) (105.6 - 132.0 litres) of UBIX No. 0010 Soil Compaction Agent diluted with the appropriate amount of water, determined by the moisture levels at the construction site, is sufficient material to construct 2.3 miles (4.65 kilometres) with a 6-inch (15 mm) base.

5.7 Technical Assistance

The Enzymes Plus Division is not engaged in the construction industry. However, we have available to us and can arrange for the support of a Registered Professional Roadway Engineer and/or Chemist Consultant, should a prospective client require technical assistance.

5.8 Shipment and Storage

UBIX No. 0010 Soil Compaction Agent is available in HDPE shipping containers in either the five (5) or fifty-five (55) gallon size. By special arrangement, the product can also be provided in totes or bulk containers. Because UBIX No. 0010 contains no toxic substances or hazardous materials, all shipping containers can be rinsed and recycled.

During shipment and storage, protect UBIX No. 0010 from temperatures 130 F (57.2 C) and above for extended periods of time as enzyme-based products tend to denature and lose efficiency at these temperatures. UBIX No. 0010 is stable under freeze/thaw conditions.

5.9 Test Reports and Studies

Copies of all test reports and studies mentioned in this Product Data Sheet are available to potential and qualified clients upon request.

5.10 F.O.B. Point (Shipping)

All shipments are F.O.B. origin, Henderson, KY 42420.

5.11 Sales Policy

Any sale of UBIX No. 0010 requires that either Civil Engineering or other type of road-building expertise be utilised on each road-building project. This policy is to ensure the proper utilisation of the product and to assure client satisfaction.

5.12 Summary

Roadway construction processes using UBIX No. 0010 Soil Compaction Agent are no different than conventional methods, except that the "Soil Compacting Agent" is substituted for the commonly used fly-ash, lime, or silicates. UBIX No. 0010 simplifies and reduces that the cost of providing a compacted base for application of a concrete or asphalt surface. Its use on farm or gravelled roads provides an erosion-resistant, more dust-free surface. In order to insure that a successful conclusion is reached on every project where this unique compaction agent is used, company policy requires that we initially provide some type of engineering support service with each sale of material.

For each project, a soil sample is to be collected and subjected to laboratory analysis in order to determine the amount of Soil Compaction Agent required. The level of engineering support offered ranges from the laboratory analysis of the soil up to and including on-site presence of a Civil Engineer familiar with the use and application of the Soil Compaction Agent as well as all other aspects of roadway construction.

Successful application of the Compaction Agent is largely dependent upon the nature of the soil at the site. The quantity of material required is a function of both the soil composition and the moisture content. This, in turn, determines the method of soil preparation, the amount of water required, the cure and construction time. For this reason, the client is asked to collect and submit a representative soil sample to be subjected to laboratory analysis to determine the quantity of compaction material required.

A flat, one-time fee will be paid by the client for the laboratory analysis. Results of the soil analysis will be forwarded by the laboratory to the civil engineer who will calculate the quantity of product and the water dilution ratio based upon the roadway dimensions provided by the client. The quantity specified will include all the compaction agent required for the road as well as the amount to be flogged onto the compacted surface after compaction is complete. This will avoid purchasing too little or too much Compacting Agent.

To insure success, the final compaction must be equal to or > 95% of the theoretical maximum soil density. For this reason, we are willing to provide prospective clients with the level of engineering assistance needed.

All field engineering services provided will be at the client's expense. These services are provided by a well-qualified registered civil engineer experienced in conventional methods of highway construction as well as in the use of the Soil Compaction Agent. His expertise will reduce the possibility of error and will assure the achievement of the desired degree of compaction.

Along with his professional capability, our civil engineer has the ability to:

- perform engineering laboratory analysis using equipment designed for on-site evaluations
- improvise and succeed under less than ideal field conditions
- use antiquated and improvised equipment in remote locations
- rework a less than well-prepared roadbed in a remote location to assure even distribution and to achieve desired
- compaction of the roadbed
- initiate efficiencies on site to reduce anticipated cost of construction
- shorten construction time reducing scheduled man hours

Envirozyme Inc. is dedicated to providing the consumer and commercial clients with safe products for individuals and earth.

All our products are "green" and provide the highest quality result with no adverse effect on our environment or inhabitants.

6. OTHER APPLICATIONS

6.1 Soil, Roadway, Foundations, Dust Abatement

Roadway construction processes using UBIX NO. 0010 is not different from conventional methods except that Compacting Agent is substituted in for the commonly used fly-ash, lime or silicate. Properly applied to a well pulverised prepared road bed, the Compacting Agent will achieve a maximum soil density equal or >95%.

For economy in transportation Soil Compaction Agent is sold as a concentrate and must be mixed with water (clean or dirty) prior to use. When water is unavailable, it can be shipped ready mixed to the construction site. Quantity determinations are made by soil analysis and are based on quantity and type of sand, the various clays and silk present, and the optimum moisture content of the soil. As an average, one (1) gallon of Compaction Agent is required for each 150 cubic yards of soil to be treated. Equipment requirements include a water meter, blader/grader, compactor and a supply of water.

Once the soil mass is wetted, the enzymes present begin to react with the humus in the soil. By the elimination of dry layers of compacted material, a hydrogel condition develops to stabilise and to form a cementitous binder between the particles and grains of the soil that will develop substantial strength within one to three hours at temperatures of 50-90°F (9-29°C). All particles will be well packed and locked together to form a solid base, protected by a water impervious very strong tight surface.

Other uses include construction of Heliports, Landing Strips, Tennis Courts, Driveways, Pond Liners, etc.

7. ENVIRONMENTAL AND SAFETY STATEMENT

UBIX products are benign; they are environmentally safe, and nontoxic or hazardous to man, flora, or aquatic life with pH levels ranging from 3.5-9. They contain no ozone depleting chemicals or substances, no solvents or terpenes (Class 1 ODS, VOCs or HAZTOXs)

All ingredients appear on the U.S. EPA TSCA inventory. None are subject to any rules or orders under TSCA and according to our review no reports or record keeping is required at this time. During the manufacturing process no now chemicals are generated.

All new products are liquid with a natural colour of brown/black none contain scenting or colour additives.

All components of UBIX proprietary formulation are organic in nature. They contain no toxins as boosters such as pigments, polymers, or metal coating chemicals. No phenyls, chlorinated compounds, phosphates, abrasives, chromates, cresols, terpines, amines, petroleum hydrocarbons, lead, mercury, cadmium, chromium and no insert fillers such as sodium chloride, sodium sulphate, sodium hydroxide, nitrates or nitrites.

UBIX enzyme-based products have been found to be free of toxic substances through independent testing that was conducted in compliance with the Federal Hazardous Substances Act under Consumer Product Safely Commission Guidelines (16CFE 1500.40, .41, and .42)(16CFR Ch., I-90, 1500.3,4) within EPA Good Laboratory Standard Practices as described at 40CFR 160 (Revised at 48FR 53946 Nov 29,1993; 54FR 53042 and F53052, effective October 16, 1989. All live animal testing was conducted on UBIX NO.0092, the only UBIX product where components are added that may offer any chance for toxicity. None was found) Referenced tests are titled and numbered as follows:

Acute Dermal Toxicity - Rabbits #9371-92

Primary Eye Irritation - Rabbits #9370-92

Acute Oral Toxicity-Rats #9369-92

Acute Primary Skin Irritation-#9539-92

Please send comments or suggestions to:

International Business Initiatives

1530 Key Boulevard, suite 714, Rosslyn, VA 22209

(703)525-2277 (telephone) (703)525-2211 (facsimile)

mail@ibicorporation.com

ROUGHTON INTERNATIONAL

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

Report VI - Appendix II
Case Studies of Soil Stabilisation

DFID Department for International Development

February 2000

Appropriate and Efficient Maintenance of Low Cost Rural Roads

Report VI - Appendix II
Case Studies of Soil Stabilisation

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/

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

REPORT VI - CASE STUDIES OF SOIL STABIILSATION

APPENDIX II - ANDERSON AFFILIATES

REPSONSE TO REPORT ON NEPAL TRIAL

TABLE OF CONTENTS

1. CASE STUDY NUMBER 1 - NEPAL DEMONSTRATION

Thank you for allowing us to offer comments on the case study prepared covering the soil stabilisation of a mountain road in Nepal using UBIX NO. 0010 Enzyme-Based Soil Compaction Agent (Stabiliser).

We trust that our comments will be considered in the light offered and that they will be carefully considered by those who wish to consider utilising UBIX NO. 0010 for the compaction of dirt roads or any of its other applications. Further, we trust our comments will provide a more in- depth understanding of the design characteristics of UBIX 10 PART I containing enzymes and PART II Binder which is used to seal the surface of a compacted roadway and for dust abatement once the roadway has been properly cured.

2. DESCRIPTION

As a general description; the enzymes present in UBIX Part I are complex colloidal chemicals consisting of large protein molecules. Within these minute cells, there are vast numbers of different kinds of enzymes, co-enzymes and co-factors. Each particular enzyme controls or brings about a particular chemical reaction utilising both oxygen and temperature to facilitate change by oxidation digestion of the organic materials encountered. For economy in shipment and

storage, the enzymes are supplied as a concentrate and must be activated by water prior to use. For the proper application of PART I containing enzymes, the following sequential process should be followed. The process described is no different than previously provided. However, in some instances it contains more detailed explanation.

2.1 Process/Application

1 Small soil samples from the project site are collected by the prospective client and, either taken to a local geo-technical laboratory for evaluation or forwarded to the engineer who is to participate on site so that a determination can be made as to whether or not the soil at the site can be compacted using UBIX 10. The sample is also evaluated to determine if it has the ability to absorb water. If soil particles cannot absorb water, UBIX should not be used. While water activates the enzymes in PART I, the water and enzyme mixture cannot react with soil particles that are not capable of absorbing water.

2 The examination of the soil samples is also used to determine whether or not the soil can support a structure. If the soil lacks cohesiveness, it is not a good candidate for compaction. If a handful of soil cannot be formed into a ball that will hold together when moistened, the soil cannot be satisfactorily compacted. High clay content soils require an extra amount of the enzymes contained in PART I as well as 10% more UBIX PART II Binder. Soils without cohesiveness are determined as unsuitable for any type of roadway, even those that will ultimately receive a concrete or asphalt wearing surface.

3. The insitu moisture level of the soil at the project site is also determined from the soil samples collected. From the result obtained, the quantity of water that will be required for the sample to reach an optimum moisture level is estimated. The estimated result applied to the volume of soil to be compacted makes it possible to determine the quantity of water that will be required for the entire project, the volume of water that must be readily available to the project when construction begins. The volume of soil to be compacted determines the quantity of UBIX PART I that will be required (multiply the width times the length times the depth) Divide the result by 150 cubic yards or 115 cubic meters to obtain the quantity of UBIX PART I that will be required for the project. One (1) gallon of UBIX PART I will compact 150 cubic yards of soil, or 3.87 litres will compact 115 cubic meters of soil. A quantity of PART II Binder equal to 1/11th of the quantity of PART I enzymes used, is the quantity of PART II Binder that will be required. Add to that quantity an additional 10%, if the soil has a high clay content.

4. Required equipment must be available to prepare the soil, pre-moisten the soil and to uniformly distribute UBIX PART I into the soil mass. Equipment consists of a motor grader, pulveriser, heavy compactor or rubber tired vehicle, a water tank truck and the volume of water determined under item 3 above must be available. The water tank truck must have a spray bar for dispensing water or an improvisation of one , i.e. a PVC pipe of the width necessary with evenly spaced water holes drilled into its full length. A water hose cannot be used as it is impossible to uniformly moisten the soil mass no matter how skilled the equipment operator. The water flow from the water tank must be measured by a water gauge or meter and recorded.(See item 6 below)

5. Once the project site has been identified, a site survey should be arranged to evaluate the presence of large rocks and stones that must be discarded, including those that may be later uncovered or disgorged by the motor grader. (Adjust the volume of soil to be compacted to accommodate the volume of rocks discarded). Evaluate the presence and abundance of inorganic rock chips and fines that have been sluffed off of hard rocks and mineral deposits. The soil around large stones cannot be compacted. Chips and fines from hard rocks or minerals cannot absorb water. If the volume is large the soil usually cannot be compacted or overcome by the importation of different soils as rock chips and fines will eventually and naturally migrate to the surface, rupturing the soil that has been compacted.

6 Pulverise the soil well and to whatever depth is necessary to assure sufficient soil is available to compact a 6-8 inch (15-20 cm) wearing surface. The soil must be loose, fluffy and workable. When pulverising the roadway bed and soil, pulverise any remnants of a previous roadway whether simply a path, animal trail, any kind of road, paved or not. Any soil that is compacted on top of naturally compacted soil or otherwise, even by footprints, will peel off with the passage of traffic. Peelage will occur in exactly the same manner as an orange peel is removed or a re-capped tire on a heavy truck will loose its tread. Once the soil mass is properly pulverised, it is to be pre-moistened, the motor grader following closely behind the water tank truck; moistening and turning the soil to uniformly spread the moisture throughout the soil mass so that water and UBIX will reach every soil particle.

7 The amount of water required for uniform moistening for the full volume of the soil mass, is determined by using the calculation made under item 3 above as to the volume of water that will be required to bring the moisture level of the entire volume of soil up toward optimum. Multiply the total volume by 2%. Subtract the number resulting from the 2% calculation from the total volume of water required for the project. As an example if the total volume of water required for the volume of soil to be compacted is 20,000 litres, 400 litres of water must be reserved for distribution of UBIX PART I into the pre-moistened soil. It is therefore imperative that the water tank be equipped with an operating flow gauge so the construction crew will know the point at which 98% of the volume of water determined under item 3 above has been used to pre-moisten the soil. Water usage reaching the 98%level also indicates the point when UBIX PART I is to be added to the remaining 400 litres of water in the water tank truck. Further, it will then also be time to begin shaping and contouring the roadway, crowning it and so forth. Never place UBIX PART I and PART II in the water tank truck at the same time as UBIX PART II will inhibit the activity of the enzymes in PART I.

8 Once activated by water and dispersed into the pre-moistened soil, the activated enzymes and water mixture, reacts with the bacteria and fungus always present in all soils. The volume present is immaterial. The “hydrogel” condition is created and begins to spread throughout the soil mass with the assistance of water and the motor grader. Without this combination of enzymes and water, the enzyme and water mixture, the chemical reaction of enzymes, water and soil, the hydrogel will not form.

9 The chemical change that produces the very light water-like gel, also reduces the surface tension of soil particles of differing sizes and shapes, allowing the soil particles to slip together more closely. This promotes greater density in the soil mass, approximately 33%, which translates into greater load bearing capacity. Compaction forces the soil particles closer together and fills most of the voids created by air and/or water. Compacting should not cease until the compacted soil at several locations exhibits a level of compaction of 95 when measured by a penetrometer or other device.

10 The construction superintendent will soon learn the number of passes that must be traversed by the water tank truck to cover the entire roadway, including the shoulders. Once the level of UBIX PART I and the water remaining in the water

tank truck is sufficient for only that number of passes, the PART II Binder is added to the water tank truck and dispersed over the soil mass. It will not only serve as a protectorant for the roadway surface but as a seal for the abatement of dust. PART II Binder will momentarily arrest the activity of a small quantity of the UBIX PART I enzymes in the top few inches of the roadway, however, enzymes so affected will be replenished when the compacted roadway is finally fogged with a highly diluted mixture of UBIX PART I and water as described under item 11 below.

11 Immediately following compaction or within 24 hours, Fog the entire roadway with a light mist of one (1) additional gallon of UBIX PART I and up to 500 gallons of water depending upon the size of the roadway. Do not flood or wash with water as it may seriously impact enzyme activity, disrupt the surface activity of PART II Binder and its ability to later control dust . The roadway surface may be carefully smoothed out at this time, if desired.

12 Allow the roadway to cure undisturbed for 72 hours while traffic is denied access. This includes animals, pedestrians, as well as vehicular traffic, even bicycles. During the 72 hours, the hydrogel will occupy any remaining spaces and very slowly solidify. The roadway will gradually shed the quantity of water used to carry and distribute UBIX PART I within the soil mass. Shedding will be in the form of surface evaporation or gravitational downward flow. With the expiration of about 92% of the curing period, the water being lost will appear only as a dampness. If the surface seems to be drying prematurely, it does not indicate that full curing has been accomplished in less than the 72 hour curing period.

Increases in strength will occur over the following days, weeks, and months unless the compacted roadway is abused by the too early admission of heavy truck traffic.

While the end result is “stabilisation or soils, when using UBIX, it is more a combination of enzyme/water activity, enzyme/water and soil activity, mechanical preparation, application and compaction. UBIX alone cannot “stabilise” soil. The chemical reaction, created by the enzymes and water, proper construction procedures, the proper and skilful use of mechanical equipment produces the desired result. Once the processes and principles are understood, the application of UBIX 10 becomes very uncomplicated.

2.2 Testing Schedule:

As a general statement, we recommend to clients who reach the point of purchasing UBIX,

that soil samples from the project site either receive a geo-technical evaluation from a local

laboratory or that they forward samples to the engineer we have customarily provided in the past to assist the client in its first use of UBIX 10, so that the engineer will know something about the soil to be compacted. This is also accomplished to calculate the quantity of water required as well as the quantity of UBIX.

The difference between in-situ moisture and optimum moisture, determines the quantity of water required for the project. Determining the quantity of water required must also take into consideration the volume of soil.

If gradation of the soil is accomplished, the engineer who is to visit will learn in advance something about particle size distribution; the soil mix, hopefully, the size and percentage of rocks or stones, the amount of clay, sand, etc. The Liquid Limit is for the visiting engineer and will show the engineer the point at which the soil will behave as a fluid, the point at which it will become unworkable and no longer cohesive. The Plastic Limit, is also for the benefit of the engineer who will visit, and is said to occur when the soil contains just enough moisture that a small amount can be rolled into an 1/8 inch diameter thread several inches long and will not break and the point where the moisture content is such that the soil particles will slide over each other yet still have appreciable cohesion. It is the point where best compaction is achieved with clayish soils.

The Plasticity Index is the numerical difference between a soil's plastic limit and liquid limit. The plastic limit also indicates soil permeability, the higher the plasticity index, and the lower the permeability.

A compaction level of 95 is mentioned in the data published and is for the purpose of establishing the level at which compaction efforts with a compactor can cease as it indicates that good compaction has finally been achieved. If application has been correctly accomplished, the compaction level will improve appreciably and not only during the curing period but over time if the roadway is not abused.

Using the penetrometer that travels with the visiting engineer, the engineer can demonstrate to the client that a compaction goal of 95 as mentioned in the data has been achieved.

We note that UBIX 10 PART I and the Binder PART II were added to a "water browser" at the same time. This is not recommended. (Reference item 10 above)

We have concerns as to whether or not there was a uniform distribution of water and UBIX PART 1 throughout the soil base and that the enzymes would have contact with every particle of soil to permit production of hydrogel.

Without even distribution of sufficient water and enzymes, it goes without saying that the soil is deprived of the chemical reaction necessary to achieve good

compaction. Heavy doses of water cannot make up for deficiencies in construction and application.

3. POST CONSTRUCTION MONITORING

We have a single request, including only a general comment. Please compare the activities listed under items 1 through 12 above with what you have reported in your Case Study as occurring in Nepal. There is absolutely no possibility that a better result than reported could have been obtained absent divine intervention. What occurred is a travesty, a serious misuse of resources with great damage inflicted on UBIX N0. 0010 that will take light years to overcome yet never possible to erase. The result manifested for all to see and, as reported, is the natural result of the hap hazard effort that occurred by the participants at project sites.

3.1 General Discussion

So long as there are minute amounts of bacteria or fungus, naturally occurring in all soils, the chemical reaction will produce the hydrogel condition. If there is contact with the enzyme/water mixture, the reactive enzyme/water mixture can then react with soil particles.

To achieve this reaction, the enzymes and water mixture must actually reach soil particles that

possess the ability to absorb water. Water in addition to activating enzymes, also serves as the delivery system for the enzymes, carrying them to receptive soil particles.

If there has been plant life of any kind in the soil, even though decaying or long ago fully decayed, it is safe to assume that bacteria and fungus are present. Humus is dead plant life that has reached its lowest level of decay brought about by time, bacteria and fungus yet will remain effective , except perhaps in the arctic Polar Regions.

Some equate “humus” not only with the dead residue of plant life that will accumulate and form a dark zone near the surface or soil horizon but will apply the term to the fine particles worn off inorganic rocks and gravel over time. This represents a true misunderstanding.

We conclude these comments with the statement that any comments you wish to make concerning the information provided will be appreciated

Once again, we very much appreciate the opportunity to present our point of view. We will respond to any questions you or others may have and would welcome a second opportunity to

construct a trafficable road in Nepal should the opportunity be presented. We have come to understand, based upon participation in this project, that a product like UBIX N0. 0010 is sorely needed in Nepal. If allowed to do so, we will make certain that more effective equipment is utilised, that there is an adequate supply of water, that the candidate soils to be compacted are

capable of compaction. Under these circumstances, the very fine qualities and capability of UBIX N0. 0010 Part I containing enzymes and Part II containing binder may be properly demonstrated. To such a project, we are willing to contribute one (1) each 55 gallon drum of UBIX 10 and the required amount of binder.

Your work and your co-operation in this matter has been very much appreciated.

Thank you.

Sincerely,

____

Lois D. Anderson
CEO & Managing Director
Anderson Affiliates, Inc.
Enzymes Plus Division
1451 Sugar Creek Boulevard
Sugar Land TX 77478 USA

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In association with
THE UNIVERSITY OF BIRMINGHAM
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THE UNIVERSITY OF NOTTINGHAM

Report VI - Appendix III
Case Studies of Soil Stabilisation

DFID Department for International Development

February 2000

Appropriate and Efficient Maintenance of Low Cost Rural Roads

Report VI - Appendix III
Case Studies of Soil Stabilisation

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

REPORT VI - CASE STUDIES OF SOIL STABIILSATION

APPENDIX III - A BRIEF NOTE ON CONVERTING DCP TEST RESULTS TO CBR AND DETERMINATION OF BALANCE NUMBER (BN).

A BRIEF NOTE ON CONVERTING DCP TEST RESULTS TO CBR AND DETERMINATION OF BALANCE NUMBER (BN).

The equivalent CBR at depth was calculated from the rate of penetration of the DCP cone through a layer (mm/blow). For example the DN_{0-100} is the rate of penetration of the DCP through layer 0-100 mm. This penetration (mm/blow) was converted into an equivalent CBR using the formula given below.

If penetration rate (DN) > 2 mm / blow   CBR = $410\ (DN)^{-1.27}$

If penetration rate (DN) < 2 mm / blow   CBR = $(66.66xDN^2)-(330xDN)+563.33$

DCP tests to 800mm was used to determine the pavement strength balance number (BN) (BN = the number of DCP blows required to reach a certain depth, expressed as a percentage of the number of DCP blows needed to penetrate the pavement to a depth of 800 mm). Pavements with a high BN_{100} (e.g. 80) are considered to be shallow pavements. i.e. 80 % of the total energy exerted on the pavement causes a penetration of only 100 mm. In real terms it means that 80 % of the structural strength of the pavement is provided through the top 100 mm. As stabilisation extended to a maximum depth of 200 mm, the average BN_{100} (standard) and BN_{200} were calculated for the left, centre line and right positions of each road section.