THE USE OF CHEMICAL STABILISERS IN LABOUR INTENSIVE ROAD CONSTRUCTION

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DECLARATION

I declare that this project report is my own unaided work. It is being submitted for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

Signed

.... on the 17th day of May 1995

Signature of candidate

ABSTRACT

Until recently use of ionic chemical soil stabilisers seemed hit or miss. The paper by Paige-Green and Bennett explains that the stabilisers work only on soils containing reactive clays. The author's findings confirm this conclusion. It was shown that a CBR test, which can be done in any road soils laboratory, can be used to measure the change in strength caused by the treatment of the soil with a chosen ionic stabiliser.

South Africa is faced with a serious unemployment problem. The World Bank and the International Labour Organisation have shown that employment in construction can be significantly increased by the use of labour instead of machinery. Field trials showed that ionic stabilisers can readily be applied labour intensively. These stabilisers could improve marginal materials to road-building standard and this could further reduce the dependence on machinery by reducing the need to transport quantities of high quality gravel.

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ABBREVIATIONS

AECI	African Explosives and Chemical Industries
CBR	California Bearing Ratio, a standardised road material shear test, reported as a percentage of the California standard
cc	Close corporation
CEC	Cation exchange capacity; the quantity of exchangeable cations available in a soil
CSIR	Council for Scientific and Industrial Research
°C	Degrees Celcius
DBSA	Development Bank of Southern Africa
DCP	Dynamic Cone Penetrometer, a portable device for measuring soil shear strength
ILO	International Labour Office
kg	kilogramme
km	kilometre
kPa	kilo Pascal
l	litre
m	metre
ml	milli-litre
mm	millimetre
m^2	square metre
m^3	cubic metre
Mod.AASHTO	Modified AASHTO, a modified version of the compaction test originally devised by the American Association of State Highway and Transportation Officials
OMC	Optimum moisture content, that moisture content at which maximum density is obtained from the Mod.AASHTO test.
OPC	Ordinary portland cement
PBFC	Portland blast furnace cement

SA	South Africa
SABS	South African Bureau of Standards
SABS 1200	South African Bureau of Standards Standardised Specification for Civil Engineering Construction
SABS 0120	South African Bureau of Standards Code of Practice for use with SABS 1200
SPP	Sulphonated petroleum product
UCS	Unconfined compressive strength, the compressive strength of an unconfined cylinder of soil, usually measured to guage the effect of a stabiliser on the soil
UIF	Unemployment Insurance Fund
UNISA	University of South Africa
Wits	University of the Witwatersrand

PREFACE

Little is known about the action of ionic chemical stabilisers on soils - why they sometimes work and sometimes don't work. Less is known about the use of these stabilisers in labour intensive road construction. This knowledge becomes important in the context of the cost-effective construction of urban and rural infrastructure.

Mr Jean Louw, currently consultant to Conaid (Pty) Ltd, whetted the author's curiosity about the action of ionic stabilisers on soils. Jean Louw's knowledge and experience of chemical stabilisers spans a period of at least 25 years, so his ideas and reminiscences were worth a great deal.

Professor R McCutcheon and Mr James Croswell are staunch advocates of the use of labour intensive construction methods. Both have done much to further the awareness of labour intensive construction as a powerful tool for the simultaneous solution of the scarcity of urban and rural infrastructure and the alleviation of poverty. Writings from the World Bank and the ILO have further heightened the author's awareness of labour intensive construction as a means of reducing unemployment and of at least partially combatting poverty.

The author obtained personal experience of the use of chemical soil stabilisers in conventional construction while working for Eskom. Eskom used ionic soil stabilisers with considerable success for road construction . the construction of terraces for buildings. The author also has strong convictions about the desirability of the increased use of labour in construction. The combination of these two approaches seemed to be a fruitful field for post graduate study.

1. INTRODUCTION

1.1 Introduction

The literature review will show that little was known about ionic chemical soil stabilisers until Paige-Green reported on laboratory based research (Paige-Green and Bennett, 1993). Until this work was published, the action of ionic stabilisers seemed to be hit or miss in that they sometimes increased soil strengths and sometimes did not react with the soil or actually decreased soil strengths.

The effects of ionic stabilisers on soils seem to be difficult to measure. In fact, several salesmen have stated that the effects of their ionic stabiliser cannot be measured in the laboratory but must be tested in the field (van Coppenhagen, 1980; and others, 1983 - 1986). This implies that a client has to accept the risk that the stabiliser may or may not work on his project and undertake full scale field trials at considerable cost, solely on the word of a salesman. Successful laboratory testing of ionic soil stabilisers would considerably reduce the cost and risk of the current field trial approach.

The use of stabilisers to improve soil characteristics is becoming increasingly more important as high quality gravels become scarce (Simonis, 1990). Ionic soil stabilisers have the potential to increase the strength of marginal gravels (Conaid, 1992) which are often relatively easy to obtain, to fulfil the requirements of the specification. In contrast, natural gravels to the same specification may have to be transported over several kilometres at considerable cost (Paige-Green 1989a and 1989b). In addition to the problem of haulage cost, good road gravels are becoming scarce and should perhaps be reserved for important high traffic volume roads (Simonis, 1990). Therefore there is a growing need to use marginal materials for increasingly stringent requirements due to increasing traffic volumes.

The literature survey will also show that no one has written about the use of ionic chemical soil stabilisers in labour-intensive road construction. It is therefore not known if these stabilisers can be applied cost-effectively in a manner compatible with labour-intensive construction methods. These problems arise in the context of the cost-effective construction of urban and rural road infrastructure.

The World Bank and International Labour Organisation have shown that employment in construction can be significantly increased by using labour instead of machinery (Allal and Edmonds, 1978; Coukis et al, 1983; McCutcheon, 1990). The combination of these two technologies, chemical soil stabilisation and labour-intensive construction, could make effective use of scarce state funding in the construction of infrastructure, while simultaneously alleviating some of the unemployment and poverty so rampant in South Africa (Ligthelm and Kritzinger-van Niekerk 1990; DBSA 1987).

1.2 Hypothesis, objectives and brief methodology

The hypothesis which this MSc project investigates is:

Chemical stabilisers can be cost effectively used in labour-intensive road construction to improve soil strengths.

The objectives of this project are to:
i) investigate the use of ionic chemical soil stabilisers in the construction of roadworks;

ii) find methods of application of the stabilisers that are compatible with labour-intensive road construction methods;

iii) obtain comparative costs of the use of stabilisers;

iv) develop appropriate specifications.

The methods used were:

1. conduct a literature survey;
2. laboratory test stabilisers;
3. develop application methods in the field.

The consequences flowing from the above will be confidence in the use of ionic stabilisers for the improvement of in situ and locally available soils and gravels to the extent that the quality norms set by specifications and good practice can be met. This could lead to:

i) eliminating the need for gravel surfacing of engineered earth roads;

ii) improving the load carrying capacity of the formation of secondary roads;

iii) reducing the need for high quality gravel for the wearing courses of secondary roads;

iv) reducing demand for the already scarce supply of good gravel;

v) making greater use of marginal materials;

vi) increasing the scope of labour-intensive construction [illegible] the construction of roads in areas of poor [illegible] the norm is to remove great quantities of t[illegible] replace it with higher quality gravel [illegible] at great cost.

vii) increasing the productive employment of labour per unit of expenditure for an equal or higher quality of road than could be achieved without the use of the ionic chemical stabilisers.

1.3 Labour-intensive construction

Extensive research by the World Bank and the International Labour Organisation (ILO) has proved that it is technically feasible to replace equipment with labour in the construction of civil engineering earthworks. The operations of excavate, load, haul, unload and spread (ELHUS) are particularly amenable. As much as 80% to 90% of the cost of road construction can technically be done by labour instead of equipment (World Bank, 1971). However, the management and organisational skills needed to achieve any appreciable levels of equipment substitution by labour need to be learned.

It has become clear that, to use labour productively, it is necessary to train a skilled worker to become technically sound and organisationally competent and thus able to direct and motivate the workers under his control. It has also been shown necessary to train engineers in the specific skills required for labour-intensive projects (McCutcheon, 1991). Success is ultimately dependent on appropriately skilled people.

In addition to the above, small pockets of gravel could be dug out by hand that would be ignored by machine intensive methods as uneconomic. If these gravels were substandard, the use of stabilisers might improve the properties sufficiently to meet the specifications. Here again the labour content could be significantly increased.

1.4 Structure of the thesis

Chapter 2, the literature review, opens with a description of stabilisation in general terms and goes on to describe several of the chemical stabilisers available in South Africa. Some of the stabilisers described are based on ion exchange reactions with the soils, while others act more like glues which bind the soil particles. Chapter 2 then describes a recent paper by Paige-Green and Bennett, which significantly develops the theories of the action of ion exchange soil stabilisers. The highlights of this paper are summarised. The nature of clays are described to clarify the complex nature of the reactions between soils and stabilisers.

This is followed by a review of some of the literature on labour intensive construction. As this thesis is about road construction, a summary of the types of roads and their material requirements is given. The point is made that as traffic volumes increase, so the costs of road construction rapidly increase due to the ever-increasing requirements of quality and quantity of earthworks and layerworks. The role that could be played by labour in the construction of roadworks is described.

Extensive laboratory testing by the author, described in Chapter 3, was preceded by a short series of initial or pilot tests to verify strategy and the choice of test procedures. The author tested the reaction of two ionic soil stabilisers on a fine clayey dolerite gravel and measured that the average California Bearing Ratio (CBR) was doubled. The test methods, results and conclusions are fully discussed in Chapter 3.

Chapter 4 describes the Mamelodi Roads Pilot Project, in which the author participated. This was an attempt to build urban roads by labour-intensive methods, aided by ionic chemical stabilisers. The success of the pilot project is discussed in terms of generally accepted international norms on labour-intensive construction. Several methods of applying stabilisers by hand were investigated during the Mamelodi Roads Pilot Project.

Chapter 5 on methods of applying chemical stabilisers describes the calculation of dosage and dilution rates. It goes on to describe machine based application of water soluble stabilisers. Three methods of labour based application of water soluble stabilisers are described: watering cans, hoses from a tank and a hand drawn water bowser. The application of powdered stabilisers, namely lime and cement, by labour-intensive methods is also described.

The costs of purchase of a wide range of stabilisers were obtained. The application rates were estimated, as often laboratory tests are required to optimise the amounts of stabiliser applied. Estimates were made of the costs of spreading the stabiliser and mixing it into the soil layer, assumed to be 150 mm thick, by both mechanical and labour-intensive methods.

Chapter 6 describes two specifications that the author has written and proposed for the labour-intensive application of chemical stabilisers to minor roadworks. The first is a "project specification" comprising variations and additions to SABS 1200 DM, which make the standard specification amenable to the hand application of stabilisers. The second is a particular specification for minor roadworks built by labour-intensive methods, using chemical stabilisers. The specification addresses matters like the classification of excavation, limitations on the use of mechanical equipment, tolerances and an appropriate bill of quantities. These specifications will enable engineers to specify both the labour-intensive construction of roadworks and the hand application of chemical stabilisers.

This thesis sets out to test the validity of the hypothesis, stated on page 2, by showing that simple comparative CBR testing could measure the improvement in strength of a soil after chemical stabilisation. Methods of applying stabilisers by labour intensive methods would be developed. Cost calculations and estimates would show that water soluble stabilisers could be applied at modest cost.

2. LITERATURE REVIEW

2.1 Introduction

This chapter opens with a description of stabilisation in general terms and goes on to describe several of the chemical stabilisers available in South Africa. Some of the stabilisers described are based on ion exchange reactions with the soils, while others act more like glues which bind the soil particles. A recent paper by Paige-Green and Bennett, which significantly develops the theories of the action of ion exchange soil stabilisers is then described. The highlights of this paper are summarised. The nature of clays are described to clarify the complex nature of the reactions between soils and stabilisers.

This is followed by a review of some of the literature on labour-intensive construction. As this thesis is about road construction, a summary of the types of roads, their material requirements and possible usage of ionic stabilisers is given.

2.2 Stabilisation

2.2.1 Introduction to stabilisation

Stabilisation in its many forms is performed on road soils primarily to reduce the costs of construction. A major component of road construction costs is the cost of the materials together with the cost of transporting them onto the roadway (Paige-Green and Bennett, 1993). In areas containing few gravels of road quality, engineers are forced to look at the alternatives of somehow treating the available soils so that roads may be built of them. The increasing difficulty of finding good quality gravels for gravel surfacing and layerworks and the growing need to conserve these materials (Simonis, 1990), has led to increased focus on the greater use of marginal materials.

In road construction, stabilisation is the process by which the properties of soils and gravels may be altered or improved to make them more useful. Two basic processes are used: the first is cementation or binding together of soil particles; the second is chemical modification of the soil to eliminate or enhance certain properties. Ionic soil stabilisers fall into this second category. Most ionic stabilisers are based upon sulphonated petroleum products, commonly abbreviated to SPPs. All ionic soil stabilisers need a certain minimum amount of clay to be effective. A more detailed examination of the literature pertaining to SPPs will be given in sections 2.2.2 and 2.2.3. Here I will deal briefly with the better known and more widely used application of lime and portland cement to road soils.

Lime is one of the earliest soil stabilisers to be used in road construction. It is generally available in South Africa in either slaked or unslaked form. Lime is not particularly costly, however, transport charges may make up a considerable portion of its delivered cost. Lime is not effective on sandy soils as it depends on the clay fraction of a soil for its effect. The action of lime is both cementing and chemical modification. The cementing action is pozzolanic: the lime reacting with the silica and alumina in the clay fraction of the soil to form calcium alumino-silica hydrates. The chemical modification is ionic in nature with calcium ions displacing sodium and hydrogen ions on the clay particle surfaces, changing the nature of the adsorbed water layers (Savage, 1986a; De Wet, 1975; Beger, Venter and Servas, 1987; Savage, 1986b).

Cement in various forms (Ordinary Portland Cement, Portland Blast Furnace Cement, Slagment, etc.) has long been used in road construction, largely to improve borderline gravels to perform acceptably as subbases and lightly trafficked base-courses. Cement works best with low cohesion gravels by binding the particles with crystal growths of dicalcium and tricalcium silicates (Savage, 1986b; Fulton, 1961). Cement may sometimes be the only stabiliser which can be effectively used to bind a particular soil, for example, sand.

Both lime and cement are used at application rates of between 1% and 5% by mass to give the needed properties. Dosage rates higher than 5% are rarely cost effective. Lime and cement stabilisation costs are in the region of R20 to R40 per cubic metre of soil stabilised (see Appendix 2), which can be reduced by the bulk purchase and delivery of the stabilising agent.

All cement and lime stabilised soils shrink upon drying. The greater strength of cement leads to larger intact blocks and wider cracks, whereas lime gives smaller and more frequent cracking. Shrinkage cracks eventually initiate failure of the road layers under traffic (Savage, 1986b).

Both slaked lime and cement are mildly caustic and attack exposed skin. Safety precautions must be taken to reduce the effects of caustic attack by the use of gloves, goggles, overalls and barrier creams. Particular attention to safety is required when unslaked lime is used because of its highly caustic properties. Unslaked lime is more dense than slaked lime and the advantages are that it is less affected by wind and contains more active ingredient, therefore less need be applied (Ballantine and Rossouw, 1972).

The usage of lime and cement as soil stabilisers is well documented and will not be further explored here.

2.2.2 Chemical stabilisers

Materials commonly known as chemical stabilisers include lignosulphonates, sulphonated petroleum products (SPP), lime and cement (CSRA, 1987, p3500-2) and products containing them and some other products difficult to categorise elsewhere. Lime and cement have already been dealt with in the previous section. The lesser known chemical stabilisers will be described in this section. The information has largely been obtained from trade literature and is thus probably biased.

i) Lignosulphonate

Lignosulphonate is the "glue" that holds wood fibres together. It is separated from the raw timber during processing of paper pulp and is usually disposed of as waste. Lignosulphonates or "lye" were first used experimentally as road binders in the 1930's (Fossberg, 1966).

Since the early 1990's African Explosives and Chemical Industries (AECI) has been marketing lignosulphonates as soil stabilisers in powdered and liquid form (50% aqueous solution) under the trade names Ababond, Saibond and Lignos. As lignosulphonate is soluble in water and therefore subject to leaching, research efforts were applied to modify the material to reduce leaching. The result was "Modlig 140" or "Modlig", which is available in liquid form only. Modlig is roughly twice the cost of Lignos. (AECI, 1991)

Lignosulphonates act as binders, dust suppressants and compaction aids on a wide range of soils. Well graded gravels with a plasticity index (PI) of between 6 and 20 are ideal. Typical application rates are 1 to 2 kg of powdered lignosulphonate dissolved in water per square metre, mixed into the top 50 to 70 mm of the wearing course of the road. Modlig can be used on its own, but due to its cost, is usually applied in conjunction with Lignos. In this case, Lignos is applied at 0.8 kg per square metre and mixed into the top of the layer, followed by Modlig at 0.4 kg per square metre sprayed across the layer as a seal. The Modlig is normally dissolved in water in the proportion 1 to 3.

Lignosulphonate is soluble in water and is subject to leaching out of the soil by rain. The susceptibility to leaching means that the product needs to be reapplied to the road surface at intervals dependent on traffic and rainfall, usually two or three times per year. The rate of application for rejuvenation is about 0.16 kg per square metre (AECI, 1991). Modlig has been modified by the action of additives and is much less susceptible to leaching, hence extending the period between applications. These products are marketed by African Explosives and Chemical Industries (AECI).

ii) Ionic chemical stabilisers

Below I will outline what is generally known about the properties and characteristics of currently available ionic chemical stabilisers. It must be borne in mind that the chemical constituents of the products are closely guarded commercial secrets and that trade literature is frequently deliberately vague. The products described are:

Reynolds Roadpacker
Ionic Soil Stabiliser (ISS)
Conaid
Roadamine
Roadbond

The first sulphonated petroleum product (SPP) introduced in South Africa was Reynolds Roadpacker. It was made from waste petrochemical products, suitably modified with chemical additives (hence the generic term "sulphonated petroleum product"). Its action was largely ion exchange. Low valency ions were displaced from the clay particle surfaces by ions of higher valency, which changed the nature of the adsorbed water (Reynolds Roadpacker, no date, about 1976). Reynolds Roadpacker also worked as a compaction aid, reducing the compactive effort needed to achieve a given soil density. The recommended dosage rates were 200 ml of Roadpacker, well diluted in water, per cubic metre of soil. The stabiliser was variable in quality, probably due to the variation in the waste raw materials.

Reynolds Roadpacker is no longer available in SA under this name.

Ionic Soil Stabiliser (ISS) which is presently marketed as a "road in a drum" seems to be the successor to Reynolds Roadpacker and is indistinguishable from its parent. It is a dark viscous fluid with a characteristic odour. It is a sulphonated oil derived from the naphthalene fraction of petroleum, with a specific gravity of 2.2 and a pH of about 1.25, therefore strongly acidic. Protective clothing and careful handling procedures are essential in its use. The recommended dosage rate is 200 ml of concentrate per cubic metre of soil. (ISS, no date).

Conaid was developed locally from the Reynolds Roadpacker technology but is made from commercially available chemicals, with quality control monitored through Rand Afrikaans University. The stabiliser is a bright deep pink in colour and has a pH of three to four, which is mildly acid. When mixed with water it foams and therefore may be attractive to labourers on a road construction site, as a laundry soap. The chemical is said to be non toxic. Conaid is ionic in action and acts as a compaction aid. The recommended dosage rate is 200 ml per cubic metre of soil. It is marketed by Conaid (Pty.) Ltd. (Conaid, no date).

Conaid has been used in the construction of 16.7 km of streets in Tshiame, near Harrismith in the Orange Free State (Conaid, 1992). The main road, a bus route, consisted of two 150 mm layers of in situ soil each treated with 30 ml of Conaid per square metre, surfaced with a 13.2 + 6.7 mm double seal. Access streets were made of a single 150 mm layer of in situ soil treated with 30 ml of Conaid per square metre, surfaced with a sand seal. Savings over the conventional design were reported to be 48.7%. The project was constructed by machine intensive methods.

Conaid was also used in the reconstruction of roads serving sugar estates in eastern Swaziland. The area is close to the Lebombo Mountain range. The geology is largely composed of basalts and dolerites. The Weinert "N" value is less than 2 and hence weathering and decomposition of rock is rapid and severe. Montmorillonite is the predominant clay mineral. Traffic on the main haulage road, part of which was rebuilt and stabilised with Conaid, comprises cane transporters (52 tonnes on 3 axles), sugar transporters (15 to 25 tonne trucks), 130 busses per day and 900 light vehicles per day. Stabilisation took place under traffic, with frequent grading to maintain the shape. Compaction was by traffic only. The Conaid treatment was reported to be highly successful and reduced maintenance costs by a large margin (Bennetts, 1991).

Roadamine was developed locally from the Reynolds Roadpacker technology and from Conaid. It is ionic in action and acts as a compaction aid. The source of raw materials is unknown but the product is variable. Roadamine is acidic with a pH of between one and two. It is marketed by Fosroc. For use in labour intensive construction, Roadamine may be a problem due to its acidity. The chemical burns holes in trousers after spillage (Langlois, 1992). The chemical looks and feels like a soap and froths considerably in water and therefore may be stolen for its apparent use for laundry. Protective clothing and strict handling precautions would seem to be essential on a construction site. The recommended dosage rate is 200 ml of Roadamine, diluted 1:200 to 1:500 with water, per cubic metre of soil (Fosroc, 1992).

Fosroc, in an article in the Municipal Engineer (Fosroc, 1991), describes the action of Roadamine, a liquid chemical compaction medium. The results of tests on several different soils before and after treatment with Roadamine are tabulated. The figures show that Roadamine increases the density and reduces the optimum moisture content of most soils, increases the unsoaked California Bearing Ratio (CBR) strengths and usually increases the Dynamic Cone Penetrometer (DCP) strengths.

Fosroc, with Roadamine and the University of Natal, has developed the use of X-ray diffraction studies of soils to accurately define those soils that respond to treatment with Roadamine (Bartholomew, 1993). Indicator tests are performed on samples of the soil. If sufficient fines are present, then X-ray diffraction measurements are done on the -0.425 mm fraction of the samples. Clay minerals and weathering patterns are identified. Minerals susceptible to stabilisation have been found empirically and are compared with the minerals found in the samples.

Roadbond was independently developed locally and uses commercially available chemical stock. Roadbond is alkaline with a pH of about 10. It is not known if

Roadbond strictly qualifies as a sulphonated petroleum product as it differs markedly from other known SPPs. Quality control is based on chemical industry norms. Roadbond is ionic in action and acts as a compaction aid. It is manufactured and marketed by Mining and Allied Chemicals (Mining and Allied Chemicals, no date). Roadbond looks and smells like a hydrocarbon and although it dissolves in water is not likely to be stolen for use in laundry. The mild alkalinity is similar to that of common soap and therefore is unlikely to cause skin irritation. This chemical is reasonably user-friendly and no special precautions seem necessary. The dosage rate is 200 ml of the concentrate per cubic metre of soil.

iii) Other stabilisers

Stabilisers which do not neatly fall into the ionic chemical stabiliser group are described below:

Roadbind

Consolid System consisting of Consolid 444, Conservex and Solidry.

Roadbind is manufactured and marketed by Mining and Allied Chemicals (as is Roadbond, described above) and is a binder, not an ionic stabiliser. It is derived from paint industry technology, is based on acrylics and after setting is therefore not subject to leaching by rainfall (Mining and Allied Chemicals, no date). Its main application is said to be as a binder to the upper layer of a wearing course. The recommended dosage rate depends on the soil grading and varies between 400 ml and 1200 ml of the concentrate per cubic metre of soil. Roadbind should be diluted 1:100 with water before application.

The Consolid System consists of three products: Consolid 444, Conservex and Solidry that are used in combination (Van Wyk and Louw, 1991). These products are difficult to classify, as will become apparent from their description which follows below.

Consolid 444, which may possibly contain an SPP, acts as a compaction aid by reducing the surface tension of the soil water. In addition it seems to produce an ion exchange reaction with certain clays. The action of the chemical with soil is irreversible. Consolid 444 has a pH of about six, is inflammable and smells of ammonia. It is applied at a rate between 400 and 800 millilitre/cubic metre. It is normally applied to a depth of 150 to 300 mm.

Conservex is a bituminous product dispersed in water. When used with Consolid 444 the bitumen adheres to the soil particles and plugs the soil capillaries, thus reducing the permeability. Conservex reduces dust formation. Strength of stabilised soil increases with time as the volatiles evaporate. Conservex has a pH of about nine (moderately alkaline) and an ammonia odour. The top 50 to 100 mm of the road is normally treated at an application rate of 4 to 40 litre/ cubic metre. The optimum rate gives the best strength and varies with soil types.

Solidry has the same active ingredients as Consolid and Conservex but, in addition, is mixed with Portland cement and lime hydrate filler. It is a powder used in quantities of 0.5% to 2.0% of soil mass and is applied to the top 50 to 100 mm. Solidry is used with Consolid 444 instead of Conservex, on certain soil types.

The Consolid System comprises the application of Consolid 444 and Conservex to silty/sandy soils in dry areas and the application of Consolid 444 with Solidry to clayey/silty soils in flooded areas. Consolid 444 and Conservex are mixed with the water in water bowsers and applied separately. Solidry is spread across the soil dry and mixed in (Van Wyk and Louw, 1991). The Consolid System is marketed by Multi Construction Chemicals of Alrode.

2.2.3 Technical literature on stabilisers

Although both the Wits and UNISA libraries were used to search for publications on ionic chemical stabilisers, no recent work was found. Work done in the period 1946 to 1951 was reported by the Road Research Laboratory (1952), but the stabilisers were resin based and were attacked by mould. This work was not followed up any further. The search continued until the 1993 Annual Transportation Convention papers were turned up. These contained the paper on "The use of sulphonated petroleum products in roads: state of the art" by Paige-Green and Bennett (Paige-Green and Bennett, 1993). This paper summarises the background to the use of and the need for chemical stabilisers in the light of the ever growing scarcity of high quality gravels. Several stabilisers were investigated. A combination of electro-chemical and X-ray diffraction soil testing methods suggested which stabilisers were suitable and indicated the dosage rate needed. Increases in soil strength were then quantified by standard CBR testing.

The cation exchange capacity (CEC) of a soil is a measure of the potential of the clay minerals to exchange cations. The paper concluded that 2:1 clay types are the only ones with useful cation exchange capacities. X-ray diffraction testing was used to identify the clay minerals and to estimate the quantities of reactive (2:1 clays) minerals. If the percentage of reactive clays was significant, then the standard SPP application rate of 200 ml/m^3 was specified, in the knowledge that the stabiliser would act as both compaction aid and stabiliser. If the reactive clay component was low then the stabiliser would only work as a compaction aid and overdosing should be avoided by specifying a dosage rate of one third of the standard application ie. some 67 ml/m^3. The paper clearly shows the lubricating effects and consequent drop in CBR strength of standard dosing (at 200 ml/m^3) of non reactive soils. One third of the dosage gave compactive benefits without reducing the strengths.

The merits of various stabilisers were studied by means of measurements of cation exchange capacity of soils before and after treatment with the stabilisers. The amount of replacement of soil cations by the stabiliser was noted; the degree of replacement showed whether the stabiliser was effective or not. Some soils were seen to react well with certain stabilisers, while others did not react at all. No estimate of strength improvement could be made from the electro-chemical testing. However, it was shown that, where the tests suggested sufficient reaction, significant increases in strength upon subsequent CBR testing were obtained.

The above paper (Paige-Green and Bennett) quite clearly explains why the Conaid treatment of the Swaziland sugar estate roads ·ɔrked so well. The predominant clay mineral was montmorillonite, which is a 2:1 or double layer clay, with a high cation exchange capacity. Ion exchange reactions could occur on a sufficiently large scale to stabilise the road gravels used.

The paper by Paige-Green and Bennett is not exhaustive and shows how little research has been performed on the use of ionic chemical stabilisers in road construction. The art of chemical stabilisation is at an early state and really needs basic research into the chemistry and physics of the action of the stabilisers on soil.

2.2.4 Nature of clays

The previous section illustrates that some knowledge of clays and their structures is necessary for an understanding of chemical soil stabilisers. All clays have a very high surface area due to their small particle size and their plate-like shape. Besides the large external surface area, certain clays have a large internal surface area due to an open crystal structure or their bellows-like structure. Clays are sheet-like crystalline minerals, generally carrying a negative charge on their surfaces. The more commonly known clays are silicate clays; non silicate clays are soil oxides of iron, aluminium, manganese, etc., which are generally impure due to their ability to incorporate foreign ions into their structures (Newman, 1987).

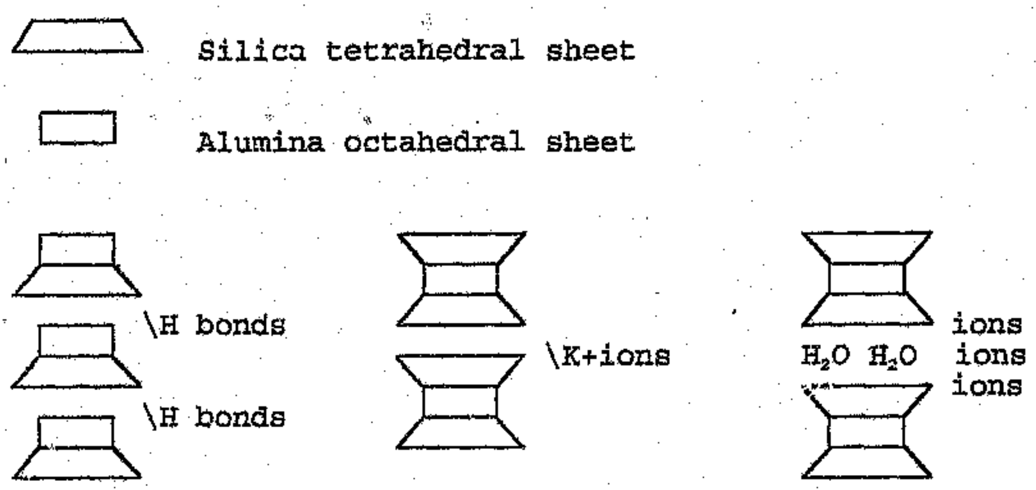
The basic structural units of silicate clays are silica tetrahedrons and alumina octahedrons, forming sheets or sheet-like crystalline structures. Silicon and aluminium may be partially replaced by other elements. When one tetrahedral sheet is linked to one octahedral sheet, a 1:1 layer is formed. When two tetrahedral sheets combine one on each side of an octahedral sheet, a 2:1 layer is formed. The sheets are tightly bonded together through oxygen atoms that are mutually shared by the silicon and aluminium atoms in their respective sheets (Newman 1987, Buckman and Brady 1968; Craig 1978).

Kaolinite comprises 1:1 layers (single sheets of silica tetrahedrons bonded to single sheets of alumina octahedrons) held fairly tightly by hydrogen bonding. Kaolinite clays are stable and of moderate cohesion.

Illite (hydrous mica) comprises 2:1 layers (single sheets of alumina octahedrons bonded between two sheets of silica tetrahedrons) held fairly weakly by non-exchangeable potassium ions. There is partial substitution of silicon by aluminium in the tetrahedral sheet. Illite is a moderately active and cohesive clay.

Montmorillonite comprises 2:1 layers (single sheets of alumina octahedrons bonded between two sheets of silica tetrahedrons). The layers are held very weakly by water molecules and exchangeable cations (other than potassium). There is partial substitution of aluminium by magnesium in the octahedral sheet. The link between the layers is so weak that the crystal lattice is bellows-like and expands very readily (Buckman and Brady 1968). This makes montmorillonite a highly expansive and cohesive clay. It should be noted that the type of linkage between the layers controls the expansiveness or stability of the clay.

Pictorially these representative clays may be shown as follows:



Kaolinite Illite Montmorillonite

Non silicate clays or soil oxides have closely packed oxygen/hydroxyl octahedral sheets as their basic units bound in layers by hydrogen bonding. Differences in the clays are due to atoms in planes being in hexagonal close packing or in cubic close packing in various combinations. Differences are also due to the positions taken up by metal cations. The crystal structures are often irregular or open, leaving spaces where metal cations can readily be held (Newman 1987). The pedogenic soils fall into this category of non silicate clays (Buckman and Brady 1968).

The negative surface charges on the clays attract cations from the pore water in the soil; as these cations are not strongly held and are in kinetic equilibrium with the soil solution, they can be replaced by other cations. The cation exchange capacity is the quantity of exchangeable cations, usually expressed as milliequivalents per 100 g of dry soil (Encyclopedia of Science and Technology, 1971).

Water molecules, being di-polar, are held in layers around the clay particles by attraction to the negatively charged surfaces. In addition exchangeable cations attract water and become hydrated. Clay particles are thus surrounded by adsorbed water. Water nearest to the clay is strongly held and the bond falls off with increase of distance from the surface.

Due to the large quantity of cations adsorbed to the surfaces of the clay layers, clays are extensively buffered against changes in pH and resist such changes (Newman 1987). The acidity or alkalinity of small quantities of chemical soil stabilisers (typical dosage is 1/8 000 to 1/10 000 of the soil mass) thus does not affect the pH of the soil. The sulphonated petroleum product stabilisers seem all to be based on ion exchange reactions where reactive ions are removed from the clay surfaces and replaced by more stable ions. This changes the water susceptibility of the clay. Less water is held by the modified clay structure, the bonds between the clay layers are enhanced and therefore the soil properties change. Other processes are probably also involved, which need to be researched so that the basic reactions can be determined.

2.3 Labour-intensive construction

The international experience in labour-intensive road construction has generally been rural and not urban. There has been general use of in situ materials and not imported gravels because of cost restrictions and low traffic volumes. This should be contrasted with the rather higher traffic volumes on roads in urban areas. Higher traffic volumes lead to a demand for higher quality materials in the roads, which usually requires the importation of gravels. Under onerous cost strictures, there is a need for simple and cheap labour-intensive stabilisation techniques, as the alternative is the much more machine intensive and costly importation of gravels.

A World Bank publication, "Labor-based Construction Programs" (Coukis et al, 1983), lays great emphasis on a governmental approach to labour-intensive construction. The book sets out the institutional requirements and support activities needed for a successful nationwide programme. It recommends that the programme start with a pilot project to better assess the costs and benefits likely to arise from a full scale programme of labour-intensive construction. Alternative construction methods are evaluated. Labour, tools, equipment and material requirements at site level are discussed. Engineering and administrative procedures and site management issues are discussed and illustrated. The many appendices add further pertinent data. The main criticism is whether this approach can be made to work in South Africa (McCutcheon, 1988) where a large part of the construction industry is in the hands of private contractors and consultants. There is not only an institutional prejudice against labour-intensive work but also legal and fiscal barriers to be overcome. Someone to champion the cause of the labour-intensive approach could make all the difference (Creswell, 1993).

In 1988 McCutcheon reported (McCutcheon, 1988) that in South Africa the creation of employment was becoming synonymous with labour-intensive construction, thus ignoring the part that could be played by other sectors of the economy. Construction should be a component of employment creation, which should be supported by all other sectors.

The (Kenyan) Rural Access Roads Programme (de Veen, 1984) is a very comprehensive introduction to the labour-intensive construction of rural roads. The book covers the management and organisation very thoroughly. Much of the wisdom contained in the book can be transferred directly to any labour-intensive construction project. However, de Veen does report on a state sponsored programme, which differs markedly from private initiative and describes the problems to be overcome in a rural roads scheme which again differs from an urban project.

McCutcheon (McCutcheon 1990) succinctly reviews the labour based road construction programmes of Kenya and Botswana and states that the reasons for the success of those programmes were:

1. The intellectual assessment of the technical feasibility and economic efficiency of using labour-intensive methods was sound.

2. Technical, organisational and socio-economic aspects received concentrated attention during a pilot project and subsequently during the establishment of a national programme. The technical matters included standards of construction, tools and equipment. Organisational aspects included institutional framework, organisation structure, management and reporting systems and training. Socio-economic issues included wage rates, labour supply, role of women and social impact.

3. Strong organisations were created with good management systems. In both programmes attention was paid to achieving a balance between the decentralisation essential for grassroots operations and the centralisation required for a national programme.

4. Training was extensive and good at what it set out to do, viz. the training of site supervisors, officers-in-charge and vehicle/ tractor drivers.

5. On balance there was long-term political support. In Kenya this was true throughout the programme, whereas in Botswana, during the early years, it was touch and go whether the support from the highest levels (President and Vice-President) and some senior district officials would outweigh the opinion of senior MPs and most senior district officials.

6. Long-term financial support was provided by government and donors.

7. On balance there was good coordination between the government, government departments, those administering the programme, local authorities, those providing technical assistance and donors. This was facilitated by the technical assistance provided by the International Labour Organisation.

In the light of the above quotation, a short term, private industry project must face many difficulties and obstacles (McCutcheon, 1993). In Chapter 4 the difficulties faced during the Mamelodi Roads Pilot Project will be compared with the above reasons for success.

An International Labour Office publication, CTP 128 (Edmonds and de Veen, 1991) emphasises the use of local resources in the construction and maintenance of roads in developing countries. Good argument is made for greater use of labour, private sector involvement and particularly small contractor development. (To date the only small contractor development programme outside South Africa has taken place in Ghana (Bentall, 1990)). Intermediate equipment and limited use of normal equipment in certain circumstances is discussed. A mixture of men and machines may be the most appropriate in certain conditions. Affordable road maintenance in relation to Gross National Product is discussed. The statement is made that low income countries may have to make harsh decisions about the size of the road network they can afford to maintain.

None of the above publications even mention the use of stabilisation, let alone ionic chemical stabilisation, for the improvement of local soils. Imported gravels are widely recommended when in situ soils are poor and cannot carry the traffic loads.

2.4 Roads

As this thesis is largely about aspects of roads and road materials, it was felt necessary to introduce the different road types which may be found. In addition, some thought is given to aspects of construction of the various road types which could benefit from the use of ionic chemical stabilisers. Labour-intensive construction techniques are disussed in the context of the road types.

Roads in South Africa range from the simplest tracks through to sophisticated highways. The author describes a more limited range of lower traffic volume roads ranging from engineered earth roads to single carriageway secondary roads. The road types are described in order of increasing traffic volumes. As the roads carry more traffic, the construction costs rapidly increase, due largely to the increasing material requirements in both quality and quantity. To this is then added the cost of material transportation which lessens the potential for a high labour content. The extent of transportation depends on the distance from the construction site to the source of the higher quality gravel. When this is coupled to a general scarcity of gravel, the transportation costs can become very high.

2.4.1 Engineered earth roads

Engineered earth roads are readily constructed by labour-intensive methods. The engineering aspects (alignment, drainage, height of formation, setting out) require a fair degree of training and experience, but the actual construction is readily carried out by people with only an agricultural background. Simple hand tools are used: picks, shovels, rakes and hoes are generally sufficient. Crowbars may be needed if rocks are encountered. (McCutcheon, 1992; De Veen, 1984). This type of road generally costs about R25 000 to R50 000 per kilometre and would carry up to 10 to 20 vehicles per day.

The engineering principles of earth road construction are well presented by Hindson (Hindson, 1983). His treatment of the problems of drainage is particularly well done and should be prescribed reading for all road engineers. However, the earth roads described are remote rural access roads carrying very low traffic volumes and hence the methods are not directly applicable to urban roads.

The construction consists of bush clearing to a predetermined width, the digging of side ditches and the building up of the formation using the soil from the side ditches. The side ditches and the formation are shaped and trimmed to the pegs and camber boards set out by the Road Builder (he is roughly equivalent to a Foreman) (McCutcheon and Marshall, forthcoming).

Careful control is kept of the camber and longitudinal profile to produce a road that will readily shed rain and will be passable at moderate speed under most weather conditions. Cross drainage is at grade and generally takes the form of rock paved drifts.

These roads are generally narrow, only 4 to 5 m wide and are often impassable during or shortly after heavy rain. Earth roads are easily damaged by heavy trucks and by prolonged rainfall and considerable maintenance is needed to keep them open to traffic (Hindson, 1983).

One of the major engineering and cost aspects of engineered earth roads was the extensive use of in situ materials to avoid importation costs and to keep the labour intensity high. The quality requirement of the in situ soil was that it had to be able to support light motor vehicles and the occassional heavier vehicle. If the soil could not provide this level of strength, then it had to be protected with a gravel wearing course, transported in at high cost. Alternatively, the load carrying capacity of the soil could be improved with sulphonated petroleum based stabilisers, without adding greatly to the cost of construction. The extra money spent on chemical stabilisers could be seen to be protecting the capital expended on construction. The additional cost of the stabiliser should be balanced by the reduced maintenance cost of the road over a moderate life span.

Most of the roads built in sub-Saharan Africa by labour intensive methods have fallen into the category of engineered earth roads. The early roads in Kenya under the Rural Access Roads Programme were built to a simple specification (de Veen, 1984). However, since 1987 the Kenyan Minor Roads Programme has moved into the gazetted road network, built to a higher standard. Methods of setting out were improved and developed for higher quality roads in Botswana, to satisfy the demands for higher speeds in the predominantly flat terrain. These methods have since been transferred to Zimbabwe to produce high standard gravelled rural roads.

There is a great need to move "up market": to tap into the funds used for the construction of roads carrying more traffic. Higher traffic volumes require stronger roads built with higher quality gravels compacted to higher densities, costing a great deal more than the low volume rural roads. If built by labour intensive methods, the construction of these roads can provide employment for a great number of otherwise unemployed people. The extent to which engineered earth road construction methods is applicable in South Africa has been documented by McCutcheon (McCutcheon, 1988) and includes low volume low cost and higher standard rural roads, low to medium volume urban roads and heavily loaded bus routes.

Some of the constraints in moving up market are the requirements for higher quality materials and higher compactive efforts, to produce the higher standard of roads. As noted above, importation of gravels is expensive and decreases the labour content, hence the successful use of chemical stabilisers in strengthening local soils and in aiding compaction, can have a major impact on both cost and employment.

2.4.2 Unpaved secondary roads

Secondary roads generally have a running surface between 8 and 12 m wide and are sufficiently strong to carry trucks and buses. The alignment should be flowing with gentle curvature (horizontally and vertically) to allow an average speed of 70 to 100 km per hour to be maintained (TRH 17, 1984). Because the formation is raised, all cross drainage must be catered for with culverts. Secondary roads are significantly more expensive than the previously described engineered earth roads, costing of the order of R250 000 per kilometre.

The formation of a secondary road can readily be constructed by the same labour-intensive methods as earth roads. The wearing course can also be constructed by labour-intensive methods, but may require more supervision to ensure that high geometric standards are achieved.

The differences between secondary and earth roads are in the standards of engineering applied and the requirement of a wearing course for a secondary road. The formation of an earth road carries the traffic loads directly, while the formation of a secondary road supports the wearing course.

Probably the most important problems concerning the wearing course are scarce resources of gravel, slipperiness, dustiness, erodibility and cost (Paige-Green, 1988). The wearing course performs several important functions and therefore should conform to strict material specifications with regard to grading, plasticity index, strength and density (Paige-Green, 1989a). Gravels with the required material properties are not readily found and hence suitable gravels are transported over long distances. This lowers the labour content, as well as adding considerably to the cost.

Gravel wearing courses erode at a rate of between 12 mm and 70 mm per year, depending on longitudinal gradient, material properties and traffic (Paige-Green, 1989b). The cost of periodically replacing this lost gravel forms a major part of the total road cost. The problems needing solution are thus the strengthening of the formation and wearing course and the enhancement of resistance to erosion of the wearing course. The costs of the solutions to the problems can be set off against the reduced capital and maintenance costs.

Depending on the soil types, chemical stabilisers may only give moderate improvements in the engineering properties of soils. Hence gravel will still need to be carried in for a wearing course. These gravels need not be of as high a quality as their properties can be enhanced by treatment with chemical stabilisers. Gravels of lower quality may be available close to the road under construction and thus be amenable to labour-intensive methods of extraction. In this regard small pockets of gravel can be dug out by hand that would be ignored by machine-intensive methods as uneconomic. Thus the overall labour content can be significantly increased.

2.4.3 Paved secondary roads

In South Africa, many secondary roads are bitumen surfaced. The surfacing is generally about 7.4 metres wide and gravel shoulders of at least 1 m width are built on each side to enhance safety. The alignment is flowing and average speeds of 100 km/hour or more can usually be achieved (TRH 17, 1984). The construction costs are generally in the range R500 000 to R750 000 per kilometre.

The formation can readily be built in the same way as secondary gravel roads. The surfacing is supported by a basecourse or by both a subbase and a basecourse, depending on the class of traffic. For very light traffic the base should have a CBR strength of not less than about 50 (Richards, 1977), but as the traffic becomes heavier, the CBR requirement increases to 80 and other material properties gain in importance (TRH 14, 1985). Here a subbase becomes essential. With careful choice of materials, ionic chemical stabilisers can readily improve gravelly soils to subbase standard (CBR = 45 or more) or to lightly trafficked basecourse standard (CBR = 50+). However, the higher standards of more heavily trafficked road bases may not be achieved. Strength alone is not the overriding criterion for these bases; durability in terms of aggregate strength and grading becomes important (Phillips, 1991).

Some types of bitumen surfacing are amenable to construction by labour-intensive methods. Single and multiple seals can be laid by hand, although the application of the bitumen itself is better done by a mechanical bitumen distributor. Hand application of the bitumen is possible with careful training and supervision. As the rate of application of bitumen by hand is more variable than by machine, a design should be chosen which is not very sensitive to these variations (Sabita, 1993).

2.5 Conclusions

The use of ionic chemical stabilisers is fairly new in road construction and their action is not yet fully understood. The scarcity of technical literature on this subject underlines the need for research into the action of these chemicals on soils. The basic reactions with clays are the exchange of reactive ions on the surfaces of the clay minerals for more stable ions from the stabiliser. Less water is held by the modified clay structure, the bonds between the crystalline clay sheets are enhanced and therefore the soil properties change.

The ILO have many years of experience in the labour-intensive construction of earth and gravel roads all over the world, yet make no mention of the use of ionic chemical stabilisers. In the author's belief this is a serious omission, taking into account the potential that the use of these stabilisers have to increase the employment of labour by enhancing soil properties and reducing gravel transportation requirements.

South Africa is faced with a serious unemployment problem. The World Bank and the International Labour Organisation have shown that employment in construction can be significantly increased by using labour instead of machinery. Labour-intensive methods can be used to achieve the same quality as equipment-intensive methods.

Rapid urbanisation has created a need for urban infrastructure. The construction of this infrastructure can be used to give gainful employment to some people in the newly urbanised areas.

The ILO have made a clear case for the use of local resources for the construction and maintenance of roads in developing countries. Labour is one of the abundant resources available. South Africa, with its burgeoning unemployment, should also make optimum use of local labour resources. However, the construction industry should not have to shoulder employment creation alone; all sectors of the economy should play their part.

In order to increase the employment potential in construction in South Africa, there are problems of institutional prejudice as well as legal and fiscal barriers to be overcome. The reasons for the success of the Kenyan and Botswana rural road construction programmes were enumerated, but these may not be easily transplanted to South Africa where a large part of the construction industry is in the hands of private contractors and consultants.

There is a need to move "up market" in labour-intensive road construction This move could tap into the funds made available for higher volume and more strategic roads and provide employment for a still greater number of people. If the use of chemical stabilisers can enhance the properties of marginal materials, then these stabilisers can further increase the role of labour in higher standard road construction.

Having discovered what was available in the literature, the next step was to carry out a series of laboratory tests to measure the effects of stabilisers.

3. LABORATORY TESTING

3.1 Introduction

There is a mystique surrounding the use of ionic chemical stabilisers in South Africa. The claims of some manufacturers or distributors have been exaggerated to the extent that no one believed that any good could come of those products. The author decided that only a practical test would prove the matter either way, or at least define the range of application. This led to the preliminary testing described below, which showed that laboratory testing does have some promise in finding whether or not a particular ionic chemical stabiliser can perform. More comprehensive testing, based on the findings of this preliminary work, was then planned.

3.2 Preliminary testing

One large sample of residual granite, comprising a fine reddish gravel with quartz and ferricrete pebbles, sieved to remove all +19 mm stone, was used. Modified AASHTO moisture / density tests were done on the natural soil. A series of unsoaked unconfined compressive strength (UCS) tests and unsoaked California Bearing Ratio (CBR) tests was done on the natural soil and on soil treated with ionic chemical stabilisers A and B. Some samples were tested immediately after compaction and some with varying periods of "cure" in a humidity room (95 to 100% humidity at a controlled temperature of between 22° and 25°C).

TABLE 3.1 UNSOAKED CBR RESULTS FOR VARIOUS PERIODS OF CURE IN HIGH HUMIDITY ROOM

DAYS CURE	0	3	4	7
NATURAL	15	-	-	25
STABIL. A	18	-	25	-
STABIL. B	28	20	-	27

TABLE 3.2 UNSOAKED UCS (kPa) RESULTS FOR VARIOUS PERIODS OF CURE IN HIGH HUMIDITY ROOM

DAYS CURE	0	3	4	7
NATURAL	440 440	-	-	510
STABIL. A	330	-	460	-
STABIL. B	380	380 440	-	530 445

The test results were scattered and only tentative conclusions could be drawn from them. These were that stabilisers A and B increased the CBR compared with the natural material, but decreased the UCS. Curing increased the effect of stabiliser A on both the CBR and UCS. However, curing of soil treated with stabiliser B decreased the CBR and increased the UCS. These results are not compatible. The number of tests done was insufficient to allow firm conclusions to be made. However, the significant conclusion that could be drawn from this series of tests was that laboratory testing of ionic stabilisers did after all look hopeful in measuring property changes in treated soils.

Another conclusion drawn from the initial testing was that the variance of the results must be reduced. Finer soils should be used which would be less susceptible to segregation. It was also concluded that soils should contain more clay to try to enhance the differences between natural and treated soil test results. Unconfined compressive strengths could be ignored as the stabilisers had only a small effect on these tests.

It was further concluded that a totally different and extended curing regime would probably be necessary to bring out the qualities of ionic chemical stabilisers. This is based on the recommendations of several manufacturers of the stabilisers that treated road layers should be wet cured for three days. They also insist that bituminous surface treatments are not to be applied until the layer has developed the "typical block-cracking pattern" upon drying out (which may take up to four weeks). A further reason for some form of extended curing is that clayey soils have low permeability and therefore the chemicals must be given time to penetrate into the clays to do their work of ion exchange.

3.3 Aim of tests

It was decided to be conservative and to choose that the tests done during this project should be based upon the normally accepted road tests. The tests should be those which could be undertaken by any road soils laboratory.

Soil tests should be done on both stabilised and untreated soils to determine the influence of chemical stabilisers on the engineering properties. The soil sample should be homogeneous so that the differences in comparative testing would not be masked by sample variation. Each test would be repeated so that the size of the variations inherent in the test could be measured. This should lead to the identification of statistically significant changes in the measured values of the engineering properties due to stabilisation.

The tests proposed for the main programme were:

Indicator (grading and Atterberg limits)
Mod.AASHTO moisture / density relationship
California Bearing Ratio (CBR).

It was expected that indicator tests would show changes to liquid and plastic limits and the plasticity index and possibly also show changes to the fine fraction of the grading. Mod.AASHTO tests would show if the stabiliser acted as a compaction aid by depressing the optimum moisture content and by increasing in the maximum density. CBR tests would show gains in strength due to any cementing action, to changes in clay chemistry and to increases in density.

3.4 Test methods

3.4.1 Preparation

A large sample (approximately one tonne) of weathered dolerite soil was obtained from a borrow pit next to Tutuka Power Station in the Standerton district. The soil is known to contain montmorillonite clay in significant quantity. As montmorillonite is a double layer (2:1) clay, it is considered active and significant reaction with the stabilisers was expected.

The sample was air dried and then sieved through a 16 mm sieve. The +16 mm portion was lightly crushed and resieved until a few hard "core stones" of unweathered dolerite remained. These were discarded. The sample was then thoroughly mixed and transferred to bins for storage.

3.4.2 Tests

All tests were done in triplicate. The tests done were:
(i) Mod.AASHTO maximum density and optimum moisture content determinations.
(ii) California Bearing Ratio tests done only at Mod.AASHTO compactive effort ie. at 100% Mod.
(iii) Indicator tests on soil from the Mod.AASHTO moisture / density test nearest to optimum moisture content.

All tests were done first on the natural (unstabilised) soil and repeated on soil treated separately with stabilisers A and B.

MOD.AASHTO

Soil for the Mod.AASHTO moisture / density test was weighed off and water and stabiliser (if required) were measured and mixed in for predetermined moisture content steps. Each sample was then stored overnight in a plastic bag to allow the water to permeate into the soil and for the stabiliser to start reacting with the clays. The following day each sample was compacted using a Farnell (Hatfield, England) compaction machine set to the Mod.AASHTO compactive effort. Densities and moisture contents were measured and plotted to determine the maximum density and optimum moisture content (OMC). Soil from the mould nearest optimum was extruded and kept for later indicator testing.

CALIFORNIA BEARING RATIO

Similarly, the CBR samples were made up with water and stabiliser (if required) to the optimum moisture content and stored overnight in plastic bags. Moisture contents were determined overnight and corrected by adding water or by extended mixing to dry out the sample as needed to bring the moisture content near to OMC. The samples were then compacted using only the Mod.AASHTO. compactive effort.

Varying curing regimes were applied in the CBR testing programme. Some specimens were sealed in plastic bags immediately after compaction and stored at room temperature for varying periods. Some specimens were air dried by being stored in their moulds on their sides on the laboratory floor for varying periods. Several combinations were run. All CBR specimens were soaked in water for four days immediately before testing.

INDICATOR TESTS

As previously referred to, indicator tests were done on soil from the mould nearest to optimum. The soils were obviously crushed to some extent by the action of the compacting hammer, so no great significance should be attached to the gradings. The prime reason for using this material instead of fresh uncompacted soil, was that the stabilisers had been intimately mixed into the soil and had considerable time to act on the soil. Indicator testing was done in September, whereas the Mod.AASHTO tests were done during July. The soil samples were allowed to dry out completely (air dried) before indicator preparation was undertaken.

Preparation and sieving were done strictly according to the requirements of TMH 1: "Standard methods of testing road construction materials", except that several additional sieve sizes were used as a comprehensive grading curve was sought.

The specific gravity of the soil passing the 0.425 mm sieve was measured. Air was removed from the samples under vacuum. Each test was duplicated and the mean value reported.

Hydrometer testing was then done to determine the finer fractions. The dispersing agent, "Calgon", was used at a dose of 125 ml per standard measuring cylinder. The hydrometer readings and the subsequent calculations were based on ASTM D422-63 in preference to TMH 1 test method A6, as greater detail was wanted. TMH 1 gives only the 0.075 mm, 0.050 mm and 0.005 mm values and does not take account of the specific gravity of the soil. The hydrometer reading intervals were chosen in such a way that the particle sizes approximately halved at each reading and ranged from 0.074 to 0.004 mm. Refer to Table 3.1 for the calculated values.

TABLE 3.3 HYDROMETER TIME INTERVALS AND PARTICLE SIZES

Time	Particle size
18 sec	0.074 mm
1 min	0.042 mm
5 min	0.019 mm
30 min	0.008 mm
120 min	0.004 mm

After corrections to the readings for cylinder cross-section, hydrometer volume and stem length, temperature, meniscus rise, deflocculating agent and specific gravity, the calculated quantities of soil fines were adjusted proportionately to the wet sieved 0.075 mm values.

Atterberg limits were also measured. The liquid limit was found using the TMH 1 test A2 'flow curve' method with at least three points. The plastic limit, TMH 1 test method A3, was duplicated in separate determinations and further checked if discrepancies arose. Linear shrinkage was also measured.

3.5 Test results

3.5.1 Mod.AASHTO

TABLE 3.4 Mod.AASHTO MAX.DENSITIES AND OMCs

SOIL	MAXIMUM DENSITY kg/cu.m	OPTIMUM MOISTURE CONTENT %
Natural	2 133 ± 6	11.3 ± 0.1
Stabilised A	2 139 ± 7	10.4 ± 0.2
Stabilised B	2 170 ± 6	10.6 ± 0

Table 3.4 shows that both stabilisers depress the optimum moisture content significantly. The table also shows the influence that stabiliser B has upon the maximum density. It raised the average unstabilised density by 1.7% (where the standard deviation is 0.3%). Stabiliser A has insignificant influence upon the maximum density, having raised the density only by one standard deviation (0.3%). The tests were triplicated and the standard deviation of 0.3% shows good consistency.

TABLE 3.5 DENSITIES OBTAINED FROM CBR SAMPLES

Soil	Average density of 15 samples kg/cu.m	Average moulding moisture content of 15 samples %
Natural	2126 ± 15	11.4 ± 0.1
Stabilised A	2141 ± 19	10.5 ± 0.3
Stabilised B	2131 ± 23	10.6 ± 0.3

Table 3.5 is based upon the moulding densities of specimens compacted at OMC for CBR testing, for five variations of curing with each test being triplicated, thus giving 15 results. Scrutiny of Table 3.5 shows the standard deviations to be much higher (0.7 to 1.1%) than Table 3.4, probably due to differences in sample composition affecting the densities, despite all efforts to reduce the variations of the soil tested. The influence of the stabilisers upon density is shown to be much smaller and more variable than given by the Mod.AASHTO testing (Table 3.4). In fact, the influence of the stabilisers upon density becomes statistically insignificant. The author feels that Table 3.5, based on 15 results for each soil treatment, is much more representative of field conditions than Table 3.4.

3.5.2 California Bearing Ratio

TABLE 3.6 CBR VALUES FOR DIFFERENT CURING REGIMES

TEST No.	1	2	3	4	5	O/A MEAN CBR VALUES
TREATMENT						
Damp cure	-	3 days	-	3 days	7 days	
Dry	-	-	3 days	7 days	7 days	
Soak	4 days	4 days	4 days	4 days	4 days	
CBR VALUES						
Natural	32± 4	34± 6	41± 4	38± 4	35± 3	36± 5
Stabil.A	67± 6	106±13	57± 8	61±12	74± 9	73±20
Stabil.B	74±10	43± 9	67±14	51± 8	79±11	63±17

The CBR values in Table 3.6 show considerable variation. The apparent increase in strength of the natural (unstabilised) soil with increased length of curing was found not to be significant at the 95% confidence level, by means of the two-sided "t" test. The same "t" test was used to check the consistency of the CBRs measured for stabiliser A and separately for stabiliser B. Test 2 (three days damp cure followed by four days soak) in each case showed up as being significantly different from the other tests in the series. In the case of stabiliser A the result was abnormally high and for stabiliser B was abnormally low. Statistical analysis of tests 1, 3, 4 and 5 using stabiliser A (and separately stabiliser B) showed that despite the individual differences between the tests, they were from the same normal distribution at the 95% confidence level. For these tests, therefore, different curing regimes had no significant influence on the CBR values.

The two-sided "t" test showed that all the tests performed with stabiliser A differed significantly from the tests on the natural soil and therefore the increased strengths were greater than could be expected due to natural variation (at 95% confidence levels). The same analysis of tests using stabiliser B, however, showed that test 2(B) was within the normal distribution of the CBRs measured on the natural soil. The remaining tests, 1,3,4 and 5 were significantly different from the natural soil tests at the 95% confidence level and therefore showed that stabiliser B raised the strength beyond the normal distribution of strengths of the natural soil. Appendix 7 summarises the statistical analyses.

Analysis of the variations in CBR is clouded by the great variation in density of the samples. Normally one expects an increase in CBR to result from an increase in density, but the results obtained do not show this trend. This may be an indication that the "bonding" of the soil due to the stabilisers has greater influence upon the CBRs than the density. Tables of all the CBRs and corresponding densities are given in Appendix 1.

The changes in moisture content during the entire curing regime show a consistent pattern. Curing in plastic caused a very small loss of moisture. The moisture lost during drying depended on the length of time the sample dried and was about 3% after seven days. Soaking for four days replaced all the moisture lost and further saturated the samples. The samples generally gained about 1% over the moulding moisture during soaking. The stabilisers clearly do not waterproof the samples in any way, as the moisture gained by the stabilised soils similar to that gained by the natural (unstabilised) soil. This is contrary to claims made by the manufacturers.

3.5.3 Indicators

When plotted, the gradings show a tendency towards gap grading, in that the curve is steep between 4.75 and 0.600 mm: the percent passing drops from 97% to 30%. Beyond 0.600 mm the curve flattens out and shows a long 'tail'. The percentage of clay (<0.005 mm) is remarkably small at around 10%, considering the stickiness of the damp soil. The stickiness is probably an indication of an active clay. The soil is known to contain significant amounts of montmorillonite (Wiid, undated).

There are no differences of any significance between tests on stabilised and unstabilised soils in grading, liquid limit or plasticity index. Therefore it seems that the chemical stabilisers have no influence on these properties of the soil. In the specific gravity test results, however, differences are apparent. The treated soil samples are heavier than the untreated soil, by 2.2% for A and 2.1% for B. The conclusion is that some change has taken place in the soil fines. The quantity of stabiliser added, however, was so small (0.6 ml stabiliser concentrate was added to each 3 litre soil sample or about 1 : 10 650 by mass) that the increase in mass is difficult to ascribe to the exchange of light cations in the soil for heavier ones from the stabiliser.

3.6 Conclusions

The primary conclusion is that both stabilisers A and B increase the CBR strength of the particular soil tested. As the soil contains montmorillonite, an active 2:1 clay, the result is to be expected in the light of the work done by Paige-Green and Bennett.

Both stabilisers reduce the optimum moisture content of the soil but have little influence on the density. Hence the stabilisers do not act as significant compaction aids on the particular soil tested. The stabilisers also have no discernible waterproofing action on the soil.

Changes in the indicator values due to the stabilisers are not significant. The plasticity index is not changed, contrary to what was expected. A small increase was noted in the specific gravity results due to both stabilisers. This increase is too large to be explained by the exchange of heavy ions from the stabilisers for lighter ions in the clays, as the mass of stabiliser added was very small.

The improvement in the engineering properties due to stabilisation of the soil tested was to upgrade the gravel classification from G6 to G5 (TRH 4), except that the plasticity index remained too high.

Having established that ionic stabilisers do increase the strength of soils (within certain limits), the next problem was to find methods of applying these stabilisers by labour intensive means. The Mamelodi experience proved invaluable in this regard and is discussed in the following chapter.

4. MAMELODI ROADS PILOT PROJECT

4.1 Introduction

Despite the paucity of international literature on urban labour intensive road construction, the author felt that many of the findings from rural road construction could be transferred directly. Further, municipal road construction experience, even though machine based, should be useful in labour intensive construction. The combination of rural labour intensive road construction skills and a knowledge of municipal construction problems, was believed to be sufficient to support an urban labour intensive road project.

The driving force behind the Mamelodi roads upgrading project was Roadbond cc (motto: "labour intensive roads with chemical technology"), a close corporation with the stated aim of developing labour intensive road construction in southern Africa. For a limited period early in the project, Roadbond cc obtained the services of Professor R T McCutcheon as specialist consultant. The project started in February 1992 with a visit to Mamelodi, a "black" town some twenty to twenty-five km east of Pretoria. This was followed by weeks of intensive planning and budgeting. When funding did not materialise, the project was put on hold. Finally in January 1993, HEKS, a Swiss church organisation, agreed to finance a pilot project to build roads in Mamelodi. The National Labour Intensive Trust was set up to oversee and administer the pilot project.

The aims of the pilot project were to initiate appropriate training of community selected local road builders to foster capacity building and skills development in Mamelodi. Within the limited time of a pilot project as much training as possible of these local road builders was to be carried out.

Further, an important objective was to show within the limits of a short pilot project that road works could be built in Mamelodi by hand with a minimum of machinery. The pilot project was to be used to advertise and demonstrate the concepts of job creation through labour intensive road construction to obtain further funding for the continuation of the Mamelodi upgrading project.

The author hac other objectives besides those of the project. First he would identify the particular problems that would be encountered in an urban setting and develop ways to overcome them. Most previous labour intensive road projects had been rurally based and there was uncertainty as to the extent to which the methods and techniques developed rurally would be applicable to an urban area. Secondly the author wished to experiment with methods of applying stabilisers compatible with labour intensive construction methods.

One of the original intentions of Roadbond cc had been to prove how well an ionic chemical stabiliser in the construction of engineered earth roads (refer African experience in low volume rural roads) would perform. Circumstances were to dictate otherwise and bituminous surfacing was forced upon the project team.

There was no communication or consultation with the Mamelodi City Council as the Council was considered illegitimate by the residents of Mamelodi. This was typical of "black" towns throughout South Africa. Some contact on purely technical matters with the City Engineer was needed and was permitted.

This was to be a short term private sector project with severely limited donor funding, unless further funding could be found. In the event, no further monies were obtained and the project finally stopped through lack of funds. Continuity of funding would have led to retention of the human resources developed during the project. The initiators still hope that a national programme will materialise to give institutional support to the efforts made at Mamelodi.

4.2 Technical matters

A major technical problem was the restricted width of the road reserve and the presence of services within it. The road reserves were generally 9 metres wide, varying from 8 to 15 metres, with some localised "choke points" of 5 and 6 metres. The engineering difficulties become apparent when a road, an open drain and a pedestrian sidewalk all have to be fitted within that space.

Each day started with loading the profiles and tools, kept in a tiny storeroom at the offices. Labourers and equipment were then ferried up to the site, some four kilometres away. Profiles were set up, work was allocated to each team and work could commence. Vegetation, rubbish and boulders were removed from the roadway. Ditches were dug to provide sufficient soil to form the shape of the road. The road was shaped to either a crossfall or camber, depending on locality, ground slope and drainage requirements. At the end of each day the tools and profiles were gathered up and returned to the storeroom at the office.

Eventually when the labour of loading, off loading and transporting the equipment became too much, a site store was acquired. Most of the equipment was then transferred to the site store. The site store comprised a 6 m long steel container that was padlocked at night.

Profiles were set up every morning and taken down every evening, a process that cost the project about one hour per day in lost production. In rural areas this is unnecessary and profiles can be left standing for as long as needed. A profile was left up overnight as an experiment: by morning it had been stolen. However, steel pegs firmly driven into the ground were not taken, although they did sometimes suffer damage. So the procedure developed was to choose the line and level for a particular stretch of roadway and to set up profiles adjusted to suit this alignment. Reference pegs were then hammered in, to establish key points and key levels. Dimensions to the pegs were recorded. When re-erecting the profiles, they were set up according to the recorded reference pegs, (occasionally) checked and then used. The repeated removal and reinstatement of the profiles caused a slow loss of accuracy, which sometimes became serious. Where possible, more permanent reference points were chosen: corner posts, the foot of a light standard, etc.

Due to the initial lack of chemical stabiliser and a suitable water tank, earthworks consisted only of digging the side drains and shaping the road. No compaction was done at this stage. When the stabiliser and a means of applying it could be obtained, it was planned to return to the start of the job. The wearing course would be loosened, stabiliser applied and mixed in and the layer properly compacted with a mechanical compactor.

On 7 April the west end of Mnisi Street was dug over and Roadbond stabiliser was applied at 20 ml per square metre by means of the 210 litre capacity drum mounted on a wheeled trolley. The stabiliser was applied to awkward corners by means of watering cans. In general the chemical was applied at a dilution of about 1 litre of concentrate to 200 litres of water. Compaction was done with a pedestrian controlled Bomag 65S roller, which proved too light for the job.

Materials in the roads were very variable. In situ soils were usually sands with silt and boulders. The gravels used to surface the roads had come from several sources over a period of perhaps thirty years and were sometimes mostly boulders. Generally the clay content was too low and the clay type unsuitable for successful ionic stabilisation.

A 500 litre plastic water tank with hoses was delivered to the site on 21 April. The tank was first filled via garden hose from a nearby house, but the filling tempo proved to be very slow. A short length of fire hose was soon found to fill the tank from a fire hydrant (with permission from the Town Engineer). The tank was placed on the back of a bakkie for convenience of filling and transportation. Hoses were led from the tank to hand held sprayers that delivered water at 10 litre/minute on average. The spread rate could be estimated by timing the application of water to previously marked out areas. However, the application was never wholly uniform despite all attempts to achieve this.

A 2,4 tonne Vibromax W251 vibrating roller was hired from M-Plant; it arrived on 26 April and was immediately inspanned to compact Mnisi Street. This roller performed excellent work and was well maintained by the hire company, in contrast to the small Bomag roller that had to be serviced and repaired on site.

It was quickly discovered that special techniques were needed to achieve the correct shape of the roads and drains. The little Bomag was eventually used exclusively to compact the drains. The big roller tended to produce undulations in the road and to flatten the crown. Oversize rocks in the layer, which sometimes initiated undulations, were dealt with either by removal or by treatment with a sledge hammer. The remaining undulations were minimised by first rolling the layer once in static mode (without vibration of the roller), raking and re-levelling and then fully compacting the layer with the vibrating roller. After four or five passes longitudinally, the roller was turned diagonally to give the last two passes of the road surface at an oblique angle. Oblique rolling of the plastic surface eliminated nearly all remaining undulations. Careful hand cutting of high spots and filling of slacks during rolling also helped very largely to produce an acceptable road surface. Deviations of the surface from a two-metre straightedge were generally between 10 and 15 mm.

Flattening of the camber was corrected by rolling from the outer road edges inwards to the crown. Constant vigilance was, however, needed to ensure that an adequate height of crown was achieved.

Several different methods were tried for the application of compaction water and of diluted stabiliser. A spray bar lying on the tailgate of the bakkie, coupled directly to the plastic water tank, proved to be the quickest method of applying water to a relatively smooth road surface. The steep gradients, however, made it essential to water only when travelling up the grade, to ensure an adequate water supply to the spray bar. Uniform application of water across the full road width was impossible. The width of the spray bar was hydraulically limited to about one metre and meant that multiple applications were needed to cover the road width.

Hoses run off the water tank from a suitably positioned vehicle proved versatile, but the spread was uneven. Watering cans, properly filled and applied to marked out areas, gave reasonably accurate application of water or stabiliser. The method was slow and needed careful supervision at the point of filling and the point of application.

Application of liquid chemical stabilisers was eventually perfected by using a purpose made water bowser comprising a 210 litre drum mounted on a two wheeled trolley and fitted with a spray bar. This device, affectionately known as the "elephant", was handled by five men. A team of five proved necessary to manhandle the weight of the fully loaded drum over the stony soils. Four passes of the elephant ensured even application of the diluted stabiliser.

The spreading and mixing into the soil of powdered stabilisers like lime or cement proved difficult, while the liquid stabilisers were much easier to handle. However, the even application and good mixing of the powders could be judged by the uniformity of the colour of the soil. Liquid stabilisers did not exhibit these colour changes.

The bituminous surfacing was eventually subcontracted to Wearing Course Surfaces of Randburg. Hand application of the tar prime from a trolley was begun on 19 May. The drums of prime were heated over an open fire.

On 26 May the subcontractor was on site to start the single seal but due to unrest in Mamelodi he could not get deliveries of either stone or bitumen before 28 May. The seal was to comprise a tack coat of 80 - 100 penetration grade bitumen applied at 1,2 litre/m^2 by a bitumen distributor, followed by 13,2 mm stone applied at 0,010 m^3/m^2 by a truck mounted chip spreader. Hand application was done in all areas inaccessible to the machinery. Bitumen was applied by hand held lance to the bellmouths and corners, but the application was not uniform. The chip spreader gave much trouble and required constant attention to keep it operating. When it finally broke down altogether, the remaining stone was spread from large shovels. The resulting hand application was more uniform than that achieved mechanically. Finally a fog spray of 30% emulsion was hand sprayed over the stone.

A short portion of road was slurried (see Appendix 5 for a description of slurry seal), but this work was done too late in the day for the emulsion to dry and the slurry to harden before nightfall. As a result the surface was extensively tracked by vehicles, pedestrian commuters, bicycles, dogs and children and looked quite unsatisfactory. The reaction of both the Trust and Roadbond cc to this example of poor workmanship (and bad timing) was to cancel all slurry work, despite pleas about the technical superiority of a cape seal.

The subcontractor came back to the site some weeks later when the stabilisation was complete, to prime and surface the remaining roads with a single stone seal. Only the ditches were slurried. Bituminous slurry was very successfully mixed in a concrete mixer towed behind a bakkie and trailer loaded with materials. The bakkie carried the bitumen emulsion and water in drums, the trailer was loaded with crusher sand and the mixer was manhandled into position beside the trailer for easy loading of materials. The slurry was wheelbarrowed into place and spread by hand. When a section was completed, the mixer was hitched up behind the trailer and the train moved on. Much less successful was an attempt to mix slurry in wheelbarrows with spades.

In subsequent months the traffic showed conclusively that the single seal was not robust. The short portion of single seal that had been slurried showed no wear at all. The Trust accepted the technical necessity and ordered the slurrying of all the roads. So eventually the technical advice of the engineers was vindicated and followed.

A local reservoir overflowed for a week and saturated a row of houses and gardens and damaged part of the newly tarred Mnisi Street. Sewage overflows in Jwaga Street kept the ditch and road edge wet for weeks and delayed construction.

Storm water ditches had in certain cases to cross roads. The difficulty was to find that combination of size and slope that allowed easy crossing of the ditches by the variety of vehicles in the area, while still containing and conveying storm water. Storm water drainage ditches on all steep slopes were lined with local stone and ditches on lesser slopes were protected with stone scour checks built at suitable spacing. Grouting of the stone linings was long delayed by the lack of cement.

4.3 Organisation and administration

Initial planning and programming were done to establish a budget and to estimate the numbers of people and skills required. This planning was not checked or updated when the Project started, nor was it corrected when people were recruited in numbers other than as planned (the actual ratio of labour to road builder was far lower at five than the twenty planned). Even after the contract staff had been appointed, updating of the initial planning was not done. Later when the decision was made to add a bituminous surfacing over the originally planned gravel surface, the initial planning was not updated. Despite the evident lack of continuity of funds, budgets were not used as a management tool and were in fact kept secret.

Mr G T Bickley, retired, and the author, both civil engineers with extensive experience in township infrastructure design and construction, were commissioned by Roadbond to act as supervising and training engineers respectively. A part-time project manager was appointed and the advice of Professor R T McCutcheon was sought on the training and organisational aspects of the pilot project.

In about November 1992, Professor McCutcheon stressed the importance of a detailed agreement or contract between the Trust and Roadbond cc, setting out the aims and full scope of the Mamelodi Roads Pilot Project. He went as far as drafting a concept agreement for discussion. No agreement between the parties was ever concluded and therefore no policy or clearly defined scope of work was available to guide the people staffing the Pilot Project.

There was no effective project management. Despite the appointment of a part-time project manager, neither the Trust nor Roadbond permitted the project manager to function as a manager, nor was his advice heeded. There was no construction background (with some notable exceptions) for most of the staff, road builders and work s. This led to a lack of appreciation of the simplest construction and administrative procedures, the need for safety, the necessity of insurance, and so on.

Tools and equipment were kept in a 6 m steel container that was padlocked at night. This site store was twice broken into. About 70% of the tools were stolen. As no insurance had been taken out, no compensation was received and only essential tools were replaced. The workforce was hindered by occasional shortages from then on. After the second break-in, a small ski-cabin was obtained and placed beside the stores container. Two labourers slept in the cabin to act as night watchmen.

At the start of construction no systems were in place. Soon however, an attendance record and corresponding wage sheets were set up. No system for tool or material requisitioning was ever put in place, despite plentiful discussion. Authorisation and payment procedures proved to be essential, as without these, no control over expenditure could be exercised.

The office staff started work any time after 9:30, which was no example to set the work force and led to problems of discipline. Construction workers were supposed to start work at 7:00. Free use was made by the office staff of construction vehicles for private use, both during working hours and weekends, which further exacerbated problems of discipline with the construction work force.

The initial budgets and initial planning (done between April and November 1992) and initial training (started in February 1993) were based upon gravel roads. The Chairman of the Trust insisted on tarred roads as a matter of political necessity. However, subsequently no planning or budgeting was carried out to take account of the bituminous surfacing and its implications.

Late delivery of Roadbond Stabiliser and of the 500 litre water tank produced inefficient working. Portions of the earthworks had to be completed before any stabilisation could be started, whereas it should have been concurrent.

Despite all the problems of the organisation and lack of management of the Project, a spirit of team work and cooperation was built up during the life of the project.

4.4 Training

The objectives of training the road builders were to give them the necessary technical and administrative skills required to fulfil their responsibilities. Training was to be largely practical in nature, with sufficient theory to explain the necessity and reasons for the major decisions that have to be made during the construction of roads by labour intensive means. The training would encourage initiative and foresight and would, by practice, give road builders confidence in their newly learned skills.

On 12 February 1993, the first potential "Road builders" were interviewed at Mamelodi and all seven candidates, preselected by the Trust staff, were accepted. Tools and equipment were bought and a carpenter was engaged to make up twenty boning rods. Adjustable profiles were designed and fifty ordered from a local firm.

Training of the road builders started on 17 February 1993 with lectures and discussions on road construction. A short section of roadway, which normally carried little traffic, was chosen for practical training. The roadway was set out by the trainee road builders, each step being explained by the training officer (the author). Part of the site was cleared and ditch excavation was started. Skills like the use of boning rods and string lines were practised. Quantity calculations and the principles of balancing cut and fill were put across. Several cross section profiles of the roadway under construction were measured and recorded.

When training of the road builders was in its fifth day, the Project Manager, with members of the Trust and of Roadbond cc, visited the site. They brought great pressure to bear upon the site engineers to employ labour immediately. Training had not yet progressed to the stage where labour was needed. Very reluctantly it was agreed to engage labourers on 1 March 1993.

The training section of roadway, all 21.4 m of it, was completed by noon on the sixth day. The seven road builders had constructed the whole road and ditches on each side using hand tools only. Few of them had been employed before, none on construction. This short piece of roadway was a source of considerable pride and satisfaction to all of them.

Attention was now given to the calculation of quantities in the classroom at the office. This proved difficult although all the road builders had a matric qualification. Calculation proved to be a weak point throughout the life of the pilot project. The reason for this might be due to the lack of technical subjects taught at black schools.

Labourers were taken on in stages and eventually numbered thirty-five, forming seven teams of five, each under a Mamelodi road builder.

Five student road builders from various towns in Kwandebele started training with the project on Monday 8 March. The "students" would be trained on the project and would later use their new skills on similar projects in Kwandebele. Their wages were to be recovered from the Kwandebele government. The students were spread among the road builders to familiarise themselves with the work methods. Later, during construction, they were occasionally taken aside and given specific lessons to clear up certain questions. This over staffing at middle level by twelve learner road builders where five would have been generously adequate, made economic efficiency impossible.

Mr.N Stoffberg, the Academic Registrar of the Pretoria Technikon, offered the help of the Technikon to the

Project. On 30 April 1993, Mr. Wynand van Wyngaard, a senior lecturer of the school of Civil Engineering of the Technikon, visited the site with a draft teaching proposal for the road builders. In brief this would comprise six modules of two days each at the Technikon during which relevant subjects would be taught. A successful examination would entitle the road builder to a certificate, of similar standing to other "short diploma courses" given from time to time by the Technikon. The offer was accepted and the course content fully discussed and revised. Three Kwandebele ro[illegible]rs and the seven Mamelodi road builders at[illegible]urse. Nine were awarded certificates.

The six two day modules comprised the following:

Soils: the emphasis was on soil tests as required for a normal road contract and included some practical laboratory work. The course content was relevant but limited.

Overlays: this covered only bitumen surfacing seals. The theoretical study was aided by laboratory work in building up a demonstration model of a double seal. The course was directly relevant to the project.

Concrete: the course was presented at the Portland Cement Institute as a level 1 introduction to concrete. No concrete work was included in the Mamelodi Project, but the course would be applicable to other projects.

Construction: this was an introduction to normal machine intensive road construction methods and plant and included a site visit. The Road Builders found it very interesting but the course was unfortunately quite irrelevant.

Survey: the course comprised basic measurement and setting out methods, use of profiles and a simple automatic level. The skills learned were practical and entirely relevant to the project.

Management: an introduction to different management styles and objectives was given. The course was highly theoretical and the relevance to a labour based project is doubtful.

More detail about the course modules is given in Appendix 6.

Noristan, a large chemical and pharmaceutical manufacturing company in the industrial area next to Mamelodi, offered to give a course in first aid to a group of workers from the project. Ten workers attended the first aid course and all eventually passed. The major problem encountered by the course leader was a lack of literacy amongst the workers attending the course. The course was relevant to construction projects of all types and many more of the workers (including the Road Builders) should have been sent on this excellent course.

Due to the intense pressure to employ labour and the inexperience of the staff, the training of the road builders suffered. The road builders were not trained in organisation or administration. The only records that received their attention were the weekly attendance sheets, which were frequently filled in only moments before being collected for wage determinations. Essential daily records that should have been entirely the responsibility of the road builders were attendance, tool records, progress and productivity. Task work was essential but was never brought into operation, despite being in the conditions of employment. Hence productivity was very low and progress slow. (The records mentioned above would have helped the transition to task work.)

The road builders received good theoretical technical training and a reasonable level of practical training in road building. However, the level of organisational and administrative skills transferred was very low, largely because there was no systematic technical or organisational recording and reporting system.

4.5 Community participation

The aims were to initiate appropriate training of local road builders selected by the community to foster capacity building and skills development in Mamelodi. Although the road builders and labourers were all residents of Mamelodi, their selection was done by the staff of the Trust, not by the community.

In many areas residents had planted grass on the sidewalks to reduce the quantity of dust arising from the gravel tracks. In other areas gardens had been planted within the road reserve. Removal of grass and cutting back of the gardens had to be negotiated with the residents before any road construction could be started. A liaison officer had been appointed by the Trust and he spent many evenings talking with the residents and explaining why their gardens needed to be trimmed back.

Arrangements had to be made to cope with vehicular and pedestrian traffic. Construction had to be largely carried out under traffic due to the unwillingness of drivers to adapt to the construction process. Taxis and delivery vehicles were the major culprits. Some local residents owned cars and their daily movements had to be allowed for. The local spaza shop had daily deliveries of fresh produce. Refuse removal that took place twice per week was a major but predictable problem. Good cooperation between the driver and the construction teams led eventually to an amicable solution. The rubbish truck was let through whenever possible and it went round the block when some critical process was in progress. Throughout the day a constant stream of pedestrians passed across the construction site: school children, shoppers, commuters and onlookers. Some of this traffic could be diverted but much simply had to be guided through the road works.

Civil unrest disrupted work a few times, often for several days at a time. After the Hani assassination the site was closed from 12 April to 20 April 1993. General unrest again closed the site between 22 and 26 April. The portion of Mamelodi where the road work was undertaken was usually quiet but did occasionally receive the attentions of rioting school children.
No work was planned for 3 May, the day after Oliver Tambo's funeral, but no trouble occurred and work was resumed the following day. Sporadic unrest occurred between 26 and 28 May but disrupted site work only to the extent that no deliveries of materials reached us.

Political party holidays and festivities also interrupted the work. Tuesday 6 April 1993 saw tents pitched in Jwaga Street and 16 June was Soweto Day. The site was closed on both occasions.

Rubbish and litter were a constant problem. Workers cleared up an area and within hours both residents AND workers had dropped further litter. A major educational programme would be needed to make any impression at all.

As mentioned previously in relation to organisation and administration, the site store was twice broken into and tools were stolen. No help was received from the police towards the recovery of the tools and so the winks and nods from the community (no overt help could be obtained due to fear and intimidation) could not be followed up. Due to financial constraints only a few essential tools were replaced which led to delays towards the end of the project.

Young children helped during construction, particularly in filling the water tank after school hours, however, this entailed riding in the back of the vehicle, which had its own dangers. In the context of good community relations, how does one cope with this? One must stay on a friendly footing with everyone, but cannot expose children to construction hazards.

A slurry seal was applied too late in the day, could therefore not be protected from traffic during the critical drying period and the subsequent indelible tracking left in the surface was wholly unacceptable. The reaction by both the Trust and Roadbond cc was such that slurry was totally rejected, despite its superior strength.

There were frequent signs of goodwill by the community towards the project. Residents provided cold drinking water to the workers on hot days. There were always friendly greetings to those involved in the work. There was sudden and widespread interest in the condition and appearance of houses, gardens and pavements after the project had progressed some way.

4.6 Conclusions

Despite the organisational and management problems, a length of roadway of about one kilometre was built in Mamelodi. Some machinery was used but was kept to the minimum. Mechanical compaction equipment proved essential for both final shaping and compaction of the soils. Successful methods of applying water and stabilisers were developed. Some problems inherent in constructing roads in an urban environment were identified and dealt with.

The roads were tarred and here too labour intensive methods were successful. Priming, chipping and slurrying were done very well by hand. The heavy application of hot bitumen by hand was not uniform and is not recommended.

The work force was trained in the techniques of road construction. However, task work was not carried out and therefore productivity was low. Administration and control of the work were not properly taught, leaving the road builders only partially trained.

A comparison with McCutcheon's seven reasons for success of the Kenya and Botswana projects follows (McCutcheon, 1990):

An intellectual assessment of the technical feasibility and economic realities was not done. Limited funding was not recognised as a constraint on many of the technical decisions. Economic efficiency was ignored and therefore several important lessons that could have been learnt from the project were missed (McCutcheon 1990).

Technical aspects received some attention but organisational and in particular socio-economic aspects were neglected. Organisational structures and procedures initiated from the construction site were largely ignored. Communication was poor in the extreme.

Training, although good in many technical aspects, was severely limited by not covering administration and, in particular, task work. The overstaffing of road builders did not further any lessons on efficient work methods, which might otherwise have been learnt.

Mamelodi is an African National Congress (ANC) stronghold. The project was supported by the local ANC politicians and officials but had no support from the town council. Monetary support was very limited, even though many organisations visited the site and promised their support.

Of the seven reasons for success listed by McCutcheon for the Kenya and Botswana projects (McCutcheon, 1990), very few could be found here.

From the laboratory work (chapter 3) and the lessons learned in Mamelodi (chapter 4) the next chapter formalises the methods of stabilisation and establishes the costs of application.

5. METHODS AND COSTS OF APPLYING STABILISERS

5.1 Calculation of dosage rate

The manufacturers of most ionic chemical stabilisers give quite specific dosage rates for their product. Most dosage rates are given volumetrically, for example 200 ml of concentrate to one cubic metre of soil, which makes the calculation of the dosage very simple. These dosage rates should be used circumspectly. Only soils containing active clays in sufficient quantity should be dosed at the standard rate. When a soil with a low clay content or low activity is to be stabilised, Paige-Greene advises (Paige-Green and Bennett, 1993) that the dosage is reduced to about one third so that the lubricating effects of the stabiliser are limited to aiding the compaction and do not reduce the strength. Overdosing with a compaction aid can lead to loss of strength due to excessive lubrication of the soil particles by the chemical.

The ideal dilution rates are usually also given by the manufacturer and typically range between 1:200 and 1:1000. However, should the soil being stabilised be wet already, little water can be added before the optimum moisture content is exceeded; therefore a more concentrated dosage of the stabiliser is required. This problem was encountered on the Mamelodi Roads Pilot Project and the concentration was increased up to 1:160 without problems. The mixing of the chemical into the soil becomes more exacting, of course, as the quantity of diluted stabiliser is quite small.

5.2 Machine intensive application

The normal method of applying liquid chemical stabilisers is by dissolving a measured quantity of the stabiliser into a water bowser and spraying the solution across a measured area of roadway. With care a reasonably uniform application at the required dosage rate can be achieved. Mixing of the solution into the soil is then done by means of a tractor-drawn plough or by a grader. Most manufacturers of the stabilisers advise that the mixture is left overnight to draw into the soil and to achieve the ion exchange reactions (Roadamine, 1990; Conaid, undated). Conventional construction methods are used to place and compact the stabilised layer.

5.3 Labour-intensive application

Several methods of application of diluted stabilisers have been suggested (during discussions with a variety of people), many of which were tried on the Mamelodi Roads Pilot Project. These were:

i Watering cans: 12 litre watering cans were used and were found highly successful for small awkward areas where other methods could not reach. However, control of the application rate of the solution of stabiliser needed attention. It was found best to clearly demarcate areas small enough for one watering can full (at the calculated dosage) and then to ensure that only one watering can was applied there and only there. For occasional awkward areas the additional supervision needed can be given, but the method does not lend itself to large areas. The application is slow and must be supervised at both the filling point and the application point.

ii Hoses run from a semi mobile tank: the tank was filled with water and the measured dose of stabiliser and the solution was applied through two hoses. Control of the application rate was difficult and could only be done approximately. The flow through the hoses was separately measured and was found to be 10 litre/minute with little variation as the head dropped. Marked out areas were watered for predetermined lengths of time. Variation of application within each area could only be judged by eye.

Applying water only by means of hoses worked well enough when the soil was very dry and had to be moistened, but the control of moisture content was not at all accurate.

iii Hand-drawn bowser: a 210 litre drum was mounted on a trolley and fitted with a spray bar (Howe: 1981). Stabiliser concentrate was measured off and poured in and the drum was filled with water and shaken to mix the solution. A team of five men was needed to handle the full drum on its trolley across the loose stoney soil. The flow was controlled with a valve on the spray bar. The trolley was run up and down the roadway at a slow pace until empty. It was found advisable to apply at least four drums full across a section as variations in the spread rate tended then to cancel out. This method was used at length on the Mamelodi Roads Pilot Project.

For all three methods above, after the solution was applied, the area was left for a while to allow the water to soak in and was then mixed with spades. The soil was generally turned over twice to achieve a fairly uniform mixture. The soil was then left overnight if possible, to be raked to shape and compacted in the morning.

iv Lime and cement were both tried at various times during the Mamelodi Roads Pilot Project with varying degrees of success. Dosage rate was calculated and the area per bag of powdered stabiliser marked out. The powder was then carefully spread in small heaps across the area and adjusted by eye until even. The stabiliser was then spread out and dug in with spades. Generally the soil was turned over four or five times before the mixture became uniform. Uniformity was judged by the colour of the soil/powder mixture. Mixing was a tedious and dusty process. Generally it was attempted to first adjust the moisture content of the soil to approach optimum before applying the stabiliser. Additional water was then added after the stabiliser had been mixed in, to finally adjust the moisture content and the soil was again mixed. Shaping and rolling followed as before. Generally there was no problem in achieving compaction in the limited time available when stabilising with cement.

5.4 Cost comparisons

In this section the typical range of the costs of stabilisation by various means is given. As each road project has unique aspects, a plea is made that the true cost for every operation and its alternatives should be determined before firm financially based decisions are made.

The costs of applying the stabilisers are based on a layer assumed to be 150 millimetres thick. The costs of purchase of a wide range of stabilisers were obtained.

A range of application rates was estimated from the available trade literature, as often laboratory tests are required to optimise the amounts of stabiliser applied. Estimates were made of the costs of spreading the stabiliser and mixing it into the soil layer, by both mechanical and labour intensive methods.

The cost calculation and all assumptions are given in Appendix 2 and only the results are tabled here. Costs are based upon prices ruling at the end of 1992.

TABLE 5.1 COST COMPARISONS OF APPLYING VARIOUS STABILISERS EXTRA OVER THE RATE FOR CONSTRUCTING THE LAYER

Stabiliser	Purchase, spread, mix cost extra over the layer cost, per cubic metre	
	Machine based	Labour based
Cement	R21.60 to R26.60	R33.19 to R41.65
Lime	R35.60 to R40.60	R47.19 to R55.65
Conaid	R6.96 to R7.96	R6.37 to R6.62
Roadamine	R3.90 to R4.90	R3.31 to R3.56
Roadbond	R5.24 to R6.24	R4.65 to R4.90
Roadbind	R10.00 to R11.00	R9.41 to R9.66
Consolid system	R20.65 to R46.00	R19.47 to R43.32
AECI Ababond system	R14.11 to R16.11	R12.93 to R13.43

From the table above it can readily be seen that stabilisation is a costly process with powdered chemicals like lime and cement, which have to be mixed into the soil separately from the water needed for compaction. Secondly, it can be seen that the labour-intensive application of these powders is considerably more expensive than machine based application. Application of water soluble stabilisers is simple and cheap and the costs of machine and hand application are similar.

To put these prices for applying, spreading and mixing stabilisers into perspective, they should be compared to the rates that would normally be paid for the substitution of the stabilised layer with gravel transported from a borrow pit. The relevant operations would be excavate and load in the borrow area, transport the gravel to the roadway, dump and spread, and the cost of removing the layer of "poor" soil from the roadway to make space for the gravel. Excavate, load, dump and spread could cost about R2.00 per cubic metre. Assuming the overhaul distance to be 5 km and the overhaul rate to be R1.20 per cubic metre kilometre, the price of transportation per cubic metre of gravel would be R6.00. Royalties might be payable to the land owner. A typical machine intensive rate for cut to spoil of the "poor" soil is R2.50 per cubic metre. Thus the extra over cost of bringing in a gravel layer and removing a layer of poor soil would be R10.50 per cubic metre, within the limitations of the assumptions. This price can be directly compared to the extra over stabilisation prices from Table 5.1.

5.5 Conclusions

Stabilisers that can be dissolved in water can readily and cheaply be applied by water bowser or watering can. Reasonable control over the application rates can be exercised. Application via a hose is much less controllable and is not recommended.

The estimated costs of applying water-soluble stabilisers by labour based methods are modest (R3.31 to R6.62 per cubic metre) compared with estimated machine based costs of replacing poor soil with imported gravel (about R10.50 per cubic metre). Powdered stabilisers like cement and lime can be applied by labour-intensive methods but the work is tedious, time consuming and costly (estimated to be R33.19 to R55.65 per cubic metre).

6. PROPOSED EARTHWORKS SPECIFICATIONS

6.1 Project specification

In the light of the author's previous experience, the literature survey, the laboratory testing and the field work in Mamelodi, a "project specification" has been written to be read together with SABS 1200 DM Earthworks (Roads, subgrade). It complies generally with the requirements laid down in SABS 0120 for project specifications and comprises variations from and additions to the standard SABS specification. The variations and additions to the standard SABS 1200 specification cover the use of water soluble chemical stabilisers in labour-intensive construction. The full specification is given in Appendix 3.

SABS 1200 DM Earthworks (roads, subgrade) is a standardised specification for civil engineering construction, issued by the South African Bureau of Standards (SABS). A standardised specification is defined as being "a specification that is published by the SABS and that so covers a particular class of civil engineering construction that the specification is generally applicable throughout the Republic of South Africa." (Ref. SABS 0120 part 1). A project specification "describes the works in general terms" and "may include clauses that amend or amplify or add to any requirement(s) of a standardised specification".

In the practice of civil engineering it has become apparent that the SABS 1200 series of standardised specifications are too broad to be used without amendment. Hence it has become good practice to issue project specifications with every SABS 1200 specification. The project specifications are used to reduce the broad scope of the standardised specification to the specific project requirements. In particular, materials always need to be addressed: sometimes to relax the requirements to allow the use of locally indigenous materials that have been proved to be successful; sometimes to choose one from a long list of approved materials (for example, the use of upvc piping for a specific job).

In labour-intensive construction there are many more items in a standardised specification that must be addressed by the project specification. The main headings of a standardised specification will be used to illustrate the process of amending a machine based specification to one which can be used in labour-intensive construction.

1. **Scope:** the scope of the specification must be amended to clearly state the intension of using labour-intensive construction methods.

2. **Interpretation:** the definitions given in the standardised specification must be closely scrutinised and amended where needed to be relevant to the chosen construction methods. Often additional definitions have to be given of new terms and concepts.

3. **Materials:** the specific project requirements with regard to materials needs to be spelled out. Additional or altered material specifications are sometimes required. Classification of materials to be excavated must take into account the limitations in strength of the human frame.

4. **Plant:** limitations on the use of contractor's machinery and equipment have to be set. This sometimes needs to be cross-referenced to the excavation material classification.

5. **Construction:** in a labour-intensive project it may be necessary to severely limit the options open to a contractor in the execution of certain tasks. This approach is preferable to exhortations to use labour "wherever possible", as excuses can always be found to evade the issue. In addition, all processes need to be scrutinised for bias towards machinery and this bias must then be removed.

6. **Tolerances:** in general the levels of tolerance prescribed in the standardised specifications will be found to be achievable by labour-intensive methods. However, realistic tolerances must be set, as the cost of complying with unrealistically tight tolerances is prohibitive.

7. **Testing:** just like the tolerances, the test requirements need to be realistically evaluated and reset where necessary. For example, density requirements for trench backfill are quoted as 90% of Mod.AASHTO maximum density (SABS 1200 DB clause 5.7.1) whereas popular theory on pipe support and earth loading is based on Proctor densities (which are lower than Mod.AASHTO). In addition, Proctor densities can be readily achieved by the use of hand stampers in trenches, whereas Mod.AASHTO densities usually require mechanical compactors to ensure compliance.

8. **Measurement and Payment:** measurement clauses in the standardised specifications are frequently coupled to the use of specific plant. All of these items need to

be identified and changed to suit labour-intensive construction techniques. Revised material classifications also must be carried across to the measurement and payment clauses and these clauses made relevant.

6.2 Particular specification

Particular specifications are specifications written for a particular application, as opposed to general specifications that can be more widely applied. A particular specification for the use of water soluble ionic soil stabilisers in labour-intensive road construction has been written by the author (see Appendix 3) and is summarised here. Headings of the specification follow those of SABS 1200 and use is made of relevant portions of SABS 1200 DA and DM.

The Specification is based upon labour-intensive construction of minor roadworks under good supervision. Excavation is classified into six types, depending on the degree of difficulty of digging. Properties are laid down for fill, selected and wearing course materials and for chemical stabilisers. Limitations are placed on the Contractor's choice of mechanical equipment. Construction is described in general terms from clearing of the site, through excavation and filling operations to stabilisation and finishing off the roadworks. Geometric tolerances and permissible deviations are given. Pay items compatible with labour intensive construction methods are described. Sufficient preliminary and general items are given to cover the requirements of small works. More substantial works will need to be supported by SABS 1200 A "General" or AA "General, Small Works".

6.3 Conclusions

Ionic chemical stabilisers clearly have a place in road construction, where local soils can be strengthened to meet the specified levels, thereby saving the costs of extensive overhaul of higher quality gravels. Many operations of road construction can be carried out by labour. Two specifications, having different approaches, have been written. The one is a project specification that is read together with SABS 1200 DM. The other is a particular specification that stands alone. Both specifications address the labour-intensive construction of water soluble chemical stabilised roadworks.

7. CONCLUSIONS

7.1 Unemployment and the link to road construction

South Africa is faced with a serious unemployment problem. The World Bank and the International Labour Organisation have shown that employment in construction can be significantly increased by using labour instead of machinery. Labour-intensive methods can be used to achieve the same quality as equipment-intensive methods and can be economically efficient. Thus significantly more employment can be generated per unit of expenditure. Rapid urbanisation has created a need for urban infrastructure. The construction of this infrastructure can be used to give gainful employment to some people in the newly urbanised areas.

Ionic chemical stabilisers have been identified as a possible way of increasing the role played by labour in road construction. Local or in situ soils can be improved to the extent that they can be used in the road formation or as wearing courses, effectively reducing the quantities of higher quality gravels that need to be transported to the road works. Depending on the soil types, ionic chemical stabilisers may only give moderate improvements in the engineering properties of soils. Hence gravel will still need to be carried in for a wearing course. These gravels may not need to be of high quality as their properties may be enhanced by treatment with ionic stabilisers. Gravels of lower quality may be available close to the road under construction and thus be amenable to labour-intensive methods of extraction. Small pockets of gravel can be dug out by hand that would be ignored by machine intensive methods as uneconomic. Thus the labour content can be significantly increased.

For a lightly trafficked bitumen surfaced road, the base should have a CBR strength of not less than about fifty. As the traffic becomes heavier, the CBR requirement increases to eighty and other material properties gain in importance. Here a subbase becomes essential. With careful choice of materials, ionic chemical stabilisers can readily improve gravelly soils to subbase standard (CBR of forty-five or more) or to lightly trafficked basecourse standard. However, the higher standards of more heavily trafficked road bases may not be achieved. Strength alone is not the overriding criterion for these bases; durability in terms of aggregate strength and grading becomes important.

Two specifications were proposed for the labour-intensive application of ionic chemical stabilisers to minor road works. First a "project specification" was presented, comprising variations and additions to SABS 1200 DM, which make the standard specification amenable to the hand application of stabilisers. Secondly a particular specification for minor road works built by labour intensive methods using chemical stabilisers, was given. The specification addresses matters like the classification of excavation, limitations on the use of mechanical equipment, tolerances and an appropriate bill of quantities.

These specifications will now make it possible for engineers to specify the use of labour and the use of ionic chemical stabilisers in constructing earthworks.

In the author's opinion, in the new South Africa labour-intensive methods should be the first choice when considering the construction of roads. Machine intensive methods should only be chosen when there are overwhelming reasons for their use.

7.2 Nature of clays and ionic soil stabilisers

Clays are sheet-like crystalline minerals of various forms, with widely varying linkages between the sheets. The type of linkage between the layers controls the expansiveness or stability of the clay and the relative ease by which ion exchange reactions can take place. Ionic chemical soil stabilisers are based on ion exchange reactions. The replacement of reactive ions by stable ions changes the water susceptibility of the clay. Less water is held by the modified clay structure, the bonds between the clay layers are enhanced and therefore the soil properties change.

Paige-Green and Bennett, in a paper on the use of sulphonated petroleum stabilisers, showed that a soil with significant amounts of reactive clays could be successfully stabilised. They concluded that only 2:1 clays had sufficient ion exchange capacity to be affected significantly by the stabilisers. They measured the increase in soil strength by standard CBR testing.

Further, Paige-Green and Bennett showed that the stabilisers acted as compaction aids on many soils but their influence upon CBR strengths was dependant upon dosage. Too high a dosage reduced the strength by over-lubricating the soils, reducing inter-particle friction that in turn lowered the CBR.

7.3 Testing

Preliminary testing of a residual granite soil was done using two ionic chemical stabilisers. The stabilisers gave a sufficient increase in unsoaked CBR strength compared to the natural material to hold out some hope of successful larger scale testing. A large sample of fine weathered dolerite gravel was obtained and prepared for testing. The soil was known to contain significant quantities of montmorillonite clays. Tests comprised Mod.AASHTO moisture / density determinations, California Bearing Ratio measurements and indicator tests.

In the Mod.AASHTO testing both stabilisers depressed the optimum moisture content significantly, but improved the maximum density by only a very small margin. All CBR tests were done on soaked samples, compacted to 100% of Mod.AASHTO maximum density. On average the stabilisers doubled the CBR strength of the material. The significant increase of CBR strength of the treated soil is in sharp contrast to **early** work done by the stabiliser manufacturers. This contrast is easily explained in the light of Paige-Green's findings (Paige-Green and Bennett, 1993) that only soils containing appreciable quantities of active clays have sufficient ion-exchange capacity to benefit from ionic chemical stabilisers. The sugar dolerite tested by the author contained 10% clay by mass, of which a significant proportion comprised montmorillonite (an active clay type) (Wiid, undated).

As has been shown by the tests performed by the author, a simple comparative CBR test which can be done in any road soils laboratory, shows the strength increase that can be obtained by treatment of the soil with an ion exchange stabiliser. It is not necessary to perform other chemical tests to find out the ion exchange capacity (however useful this information may be to a better understanding of the chemical process).

The increase of moisture content during soaking clearly showed that the stabilisers did not waterproof the soils in any way. Indicator tests showed that the stabilisers had little influence over the standard properties measured. In particular the plasticity index was unchanged.

The conclusion drawn was that comparative standard soaked CBR testing on stabilised and untreated soils would show conclusively if the soil could be improved by chemical stabilisation.

7.4 Mamelodi

Several methods of applying compaction water and diluted stabiliser to the roadway were tried during the course of the Pilot Project. Two methods of labour based application of water soluble stabilisers were found successful: the use of watering cans and a hand drawn bowser comprising a 210 litre drum mounted on a trolley and fitted with a spray bar. These methods allowed control of the chemical application.

Application of powdered stabilisers, namely lime and cement, by labour-intensive methods was a tedious and dusty proce/ . The quality of the result was acceptable but the process too long and drawn out for productive work. Liquid stabilisers were much easier to handle. However, the even application and good mixing of the powders could be judged by the uniformity of the colour of the soil. Liquid stabilisers did not exhibit these colour changes.

The Mamelodi Roads Pilot Project was built with a minimum of machinery. Mechanical compaction equipment proved essential for both final shaping and compaction of the soils. The pilot project was used to advertise and demonstrate the concepts of job creation through labour-intensive road construction, but very little further funding was received during 1993. The work force was trained in the techniques of road construction. However, task work was not carried out and therefore productivity was low. Administration and control of the work were not properly taught, leaving the road builders only partially trained.

Despite the organisational and management problems, about one kilometre of roadway was built in Mamelodi. The roads were tarred and here too labour-intensive methods were successful. Priming, chipping and slurrying were done very well by hand. Some problems inherent in constructing roads in an urban environment were identified, namely: narrow road reserves, obstructing services and construction under pedestrian and vehicular traffic.

The Mamelodi Project was compared with internationally accepted norms for the success of labour-intensive projects and was found wanting. The Project was not part of a national scheme, but was a donor funded private initiative and therefore does not easily fit into the pattern, nevertheless much could have been done better. Prior agreement as to sensible objectives, terms of reference, followed by proper management, better organisation, less haste and therefore more and better training would have resulted in a far more successful project.

7.5 Cost of application of stabilisers

Estimates were made of the costs of purchasing, spreading and mixing stabilisers into the soil layer, assumed to be 150 mm thick, by both mechanical and labour-intensive methods. Costs per cubic metre clearly showed that the total cost of powdered stabilisers that have to be applied separately from the compaction water (as opposed to being dissolved in the compaction water) is several times more expensive than water soluble stabilisers. The labour-intensive application of these powders was also more costly than machine based application.

Application of readily soluble stabilisers is cheap and the costs of machine and hand application are very similar. The estimated costs of applying these stabilisers are modest compared with estimated costs of removing a layer of poor soil and procuring and transporting a replacement layer of gravel.

7.6 Conclusion

The primary objective of this project was to discover if ionic chemical stabilisers could be used cost effectively in labour-intensive road construction. This has been done by:

i) successfully laboratory testing the use of two chemical stabilisers on one soil type, showing that they can be used in the construction of road works;

ii) demonstrating in the field methods of application of chemical stabilisers that are compatible with labour-intensive road construction methods;

iii) showing that the cost of applying water soluble ion exchange stabilisers is modest and therefore is a cost-effective way of improving the strength of suitable soils.

The implications are that the costs of road construction can be reduced by improving local soils and gravels (within severe limits of clay types in the soil) instead of transporting high quality gravels over extended distances. With careful choice of materials, ionic chemical stabilisers can readily improve gravelly soils to subbase standard or to lightly trafficked basecourse standard. However, the higher standards of more heavily trafficked road bases may not be achieved. The labour content of road construction can be increased as ionic stabilisers can readily be applied by hand.

The World Bank and the International Labour Organisation have shown that employment in construction can be significantly increased by using labour instead of machinery. It was also shown that labour-intensive methods can be used to achieve the same quality as equipment-intensive methods and can be economically efficient. Thus significantly more employment can be generated per unit of expenditure.

The two specifications proposed, which deal with the labour-intensive application of ionic chemical stabilisers to minor road works, will enable engineers to specify the use of labour and ion exchange stabilisers for the construction of earthworks for roads.

7.7 Further research

Further research is needed into the action of ionic soil stabilisers on soils of various types. The fundamental chemical and physical reactions need to be identified and understood. Identification will be complicated by the variability of natural soils and the difficulties of measuring their chemical constituents.

The influence of dosage rates of ion exchange stabilisers on different soil types needs to be investigated. Paige-Green (Paige-Green and Bennett, 1993) has already done some work in this direction. Further work should be coordinated.

Full scale field trials should be carried out to establish whether or not laboratory tests, as described in this project report, measure the full potential of ionic chemical stabilisation. These trials should also allow direct comparison of treated and untreated portions of roadway. The influence of the stabilisers on other qualities needed for unsurfaced roads, like resistance to potholing and erosion, could be investigated at the same time.

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APPENDIX 1 TEST RESULTS

TABLE A1.1 DENSITIES AND MOULDING MOISTURE CONTENTS RELATED TO CBR VALUES, UNSTABILISED

Soil	CBR	Cure d	Dry d	Soak d	Dry Density kg/m3	Moulding Moisture %
Natural	27	0	0	4	2 126	11.4
	33	0	0	4	2 131	11.2
	35	0	0	4	2 140	11.2
	37	3	0	4	2 132	11.5
	38	3	0	4	2 152	11.3
	27	3	0	4	2 139	11.6
	45	0	3	4	2 123	11.3
	39	0	3	4	2 102	11.4
	38	0	3	4	2 119	11.4
	35	3	7	4	2 102	11.3
	42	3	7	4	2 130	11.2
	38	3	7	4	2 129	11.3
	35	7	7	4	2 116	11.3
	32	7	7	4	2 138	11.4
	37	7	7	4	2 104	11.6

TABLE A1.2 DENSITIES AND MOULDING MOISTURE CONTENTS RELATED TO CBR VALUES, STABILISER A

Soil	CBR	Cure d	Dry d	Soak d	Dry Density kg/m3	Moulding Moisture %
Stabil A	64	0	0	4	2 170	10.6
	74	0	0	4	2 174	10.0
	64	0	0	4	2 137	10.5
	112	3	0	4	2 152	10.0
	115	3	0	4	2 158	9.8
	91	3	0	4	2 136	10.3
	49	0	3	4	2 149	10.8
	56	0	3	4	2 156	10.9
	65	0	3	4	2 140	10.8
	69	3	7	4	2 129	10.3
	67	3	7	4	2 107	10.4
	47	3	7	4	2 111	10.7
	77	7	7	4	2 139	10.6
	82	7	7	4	2 124	10.4
	63	7	7	4	2 139	10.7

TABLE A1.3 DENSITIES AND MOULDING MOISTURE CONTENTS RELATED TO CBR VALUES, STABILISER B

Soil	CBR	Cure d	Dry d	Soak d	Dry Density kg/m3	Moulding Moisture %
Stabil B	78	0	0	4	2 160	10.4
	63	0	0	4	2 165	10.5
	81	0	0	4	2 172	10.4
	33	3	0	4	2 121	11.3
	51	3	0	4	2 117	10.8
	46	3	0	4	2 119	10.9
	82	0	3	4	2 117	10.6
	55	0	3	4	2 143	10.6
	65	0	3	4	2 103	10.9
	46	3	7	4	2 146	10.7
	46	3	7	4	2 129	10.8
	60	3	7	4	2 140	10.5
	69	7	7	4	2 104	10.8
	91	7	7	4	2 107	10.3
	78	7	7	4	2 115	10.1

TABLE A1.4 CHANGES IN MOISTURE CONTENT DURING CURING, UNSTABILISED

Soil	Moulding moisture	Cure d	MC. %	Dry d	MC. %	Soak d	MC. %
Natural	11.4	0	-	0	-	4	-
	11.2	0	-	0	-	4	-
	11.2	0	-	0	-	4	-
	11.5	3	-	0	-	4	12.1
	11.3	3	-	0	-	4	11.9
	11.6	3	-	0	-	4	12.1
	11.3	0	-	3	9.1	4	12.1
	11.4	0	-	3	9.2	4	12.4
	11.4	0	-	3	9.2	4	12.3
	11.3	3	11.2	7	7.5	4	12.3
	11.2	3	11.1	7	7.5	4	12.3
	11.3	3	11.2	7	7.5	4	12.2
	11.3	3	11.2	7	7.4	4	12.1
	11.4	3	11.3	7	7.5	4	12.2
	11.6	3	11.5	7	7.8	4	12.4

TABLE A1.5 CHANGES IN MOISTURE CONTENT DURING CURING, STABILISER A

Soil	Moulding moisture	Cure d	MC. %	Dry d	MC. %	Soak d	MC. %
Stabil A	10.6	0	-	0	-	4	11.4
	10.0	0	-	0	-	4	11.1
	10.5	0	-	0	-	4	11.8
	10.0	3	9.9	0	-	4	11.4
	9.8	3	9.7	0	-	4	11.3
	10.3	3	10.2	0	-	4	11.7
	10.8	0	-	3	9.0	4	11.9
	10.9	0	-	3	9.0	4	12.1
	10.8	0	-	3	9.0	4	12.3
	10.3	3	10.1	7	7.3	[illegible]	11.8
	10.4	3	10.2	7	7.[illegible]	[illegible]	11.9
	10.7	3	10.5	7	7.4	[illegible]	12.0
	10.6	3	10.4	7	7.6	4	11.9
	10.4	3	10.2	7	7.5	4	12.1
	10.7	3	10.6	7	7.6	4	11.9

TABLE A1.6 CHANGES IN MOISTURE CONTENT DURING CURING, STABILISER B

Soil	Moulding moisture	Cure d	MC. %	Dry d	MC. %	Soak d	MC. %
Stabil B	10.4	0	-	0	-	4	11.2
	10.5	0	-	0	-	4	11.4
	10.4	0	-	0	-	4	11.2
	11.3	3	11.3	0	-	4	12.2
	10.8	3	10.8	0	-	4	11.8
	10.9	3	10.9	0	-	4	11.9
	10.6	0	-	3	8.7	4	12.1
	10.6	0	-	3	8.6	4	12.2
	10.9	0	-	3	8.9	4	12.4
	10.7	3	10.6	7	7.5	4	11.7
	10.8	3	10.7	7	7.6	4	12.2
	10.5	3	10.4	7	7.4	4	11.7
	10.8	3	10.6	7	7.8	4	12.2
	10.3	3	10.2	7	7.5	4	11.8
	10.1	3	10.0	7	7.1	4	11.7

TABLE A1.7 INDICATOR RESULTS, UNSTABILISED

SAMPLE DESCRIPTION: Sugar dolerite from Standerton District

SAMPLE NUMBER	1 N	2 N	3 N
% PASSING SIEVE 19.0 mm			100.0
13.2	100.0	100.0	99.8
9.50	99.6	99.5	99.7
6.70	98.8	98.7	99.1
4.75	96.7	96.7	97.3
2.36	76.2	76.5	78.8
1.18	44.3	44.3	48.1
0.600	30.0	29.6	33.0
0.425	27.4	26.2	29.5
0.300	24.6	24.1	26.5
0.150	20.7	20.1	21.9
0.075	17.5	16.8	18.3
0.045	15.2	14.6	16.1
0.020	13.2	12.3	13.8
0.009	12.2	11.6	13.7
0.004	10.8	10.2	11.7
ATTERBERG LIMITS Liquid limit %	44	44	44
Plasticity index	18	17	18
Linear shrinkage	10.1	9.1	9.9
SPECIFIC GRAVITY	2.807	2.780	2.725

TABLE A1.8 INDICATOR RESULTS, STABILISER A

SAMPLE DESCRIPTION: Sugar dolerite from Standerton District

SAMPLE NUMBER	1 A	2 A	3 A
% PASSING SIEVE 19.0 mm			100.0
13.2	100.0	100.0	99.5
9.50	99.7	99.9	99.0
6.70	98.3	99.0	98.0
4.75	-	97.0	96.4
2.36	77.1	74.7	76.2
1.18	43.9	42.4	44.1
0.600	29.1	27.6	29.5
0.425	25.2	24.2	26.2
0.300	23.7	22.2	23.7
0.150	20.0	18.1	19.6
0.075	16.7	14.7	16.2
0.045	14.5	12.9	14.1
0.020	12.5	11.0	11.9
0.009	10.4	9.3	10.0
0.004	9.4	8.3	9.7
ATTERBERG LIMITS Liquid limit %	45	43	43
Plasticity index	19	17	18
Linear shrinkage	9.7	8.7	8.5
SPECIFIC GRAVITY	2.810	2.835	2.849

TABLE A1.9 INDICATOR RESULTS, STABILISER B

SAMPLE DESCRIPTION: Sugar dolerite from Standerton District

SAMPLE NUMBER	1 B	2 B	3 B
% PASSING SIEVE 19.0 mm			
13.2	100.0	100.0	
9.50	99.4	99.9	100.0
6.70	98.1	99.0	98.9
4.75	96.1	97.0	96.4
2.36	76.0	75.3	75.8
1.18	44.3	42.7	43.7
0.600	29.9	28.4	29.4
0.425	25.7	25.7	25.4
0.300	24.2	23.1	23.7
0.150	20.1	19.5	19.7
0.075	16.6	16.5	16.2
0.045	14.5	14.8	14.1
0.020	12.4	12.8	12.1
0.009	10.5	10.8	10.2
0.004	9.3	9.6	8.9
ATTERBERG LIMITS Liquid limit %	45	45	45
Plasticity index	18	21	19
Linear shrinkage	10.7	9.2	10.0
SPECIFIC GRAVITY	2.820	2.839	2.825

APPENDIX 2

APPROXIMATE COSTS OF APPLYING STABILISERS EXTRA OVER NORMAL COSTS OF WORKING THE LAYER

Layer assumed to be 150 mm thick

The purchase costs of all stabilisers are based on late 1992 prices on the Witwatersrand. Quantity discounts can sometimes be negotiated. Transportation charges for other areas should be added.

POWDERED STABILISERS

Assumed application rate of cement and of lime: 3.5% of 2 000 kg/m^3 (assumed density of layer) = 70 kg/m^3

Spreading cost:

Machine intensive:

R2.00 (low) to R5.00 (high) per m^3 for cement and
R3.00 (low) to R7.00 (high) per m^3 for lime (1992 tender prices).

Labour intensive:

One man can spread powder across about 100 m^2 per hour ie. about 650 m^2 in a 6.5 hour day (estimate based on personal experience of lime stabilisation on the Mamelodi Pilot Project)

Mixing in the powder will progress at about 2 m^3 per man day, turned over about five times (estimate derived from De Veen, Kenya, modified by personal experience on the Mamelodi Pilot Project).

650 m² x 0.15 m = 97.50 m³
@ 2 m³/man day, this will need 48.75 (say 49) men.
Total manpower to treat 650 m² is thus 1 + 49 = 50 in one day.

Labour wage rate: low = R20.00 per day
high = R35.00 per day
(approximate going rate end 1992/early 1993)

On costs are: 10% for protective clothing, insurance, UIF, Workmens compensation, etc (contractor estimate)

Gang leader in charge of 20 men costs R50/20 per labourer per day = R2.50

Supervisor in charge of 100 men costs R200/100 per labourer per day = R2.00

Hence total cost per labourer becomes = wage + on costs + gang leader + supervisor
Low: R20.00 + R2.00 + R2.50 + R2.00 = R26.50 per day
High:R35.00 + R3.50 + R2.50 + R2.00 = R43.00 per day

The cost of 50 men spreading and mixing powder into 97.50 m³ thus becomes: 50 x rate x quantity

Low: 50 x R26.50 x 97.5 = R1 325.00
High: 50 x R43.00 x 97.5 = R2 150.00
ie. R13.59 to R22.05 per m3

LIQUID STABILISERS

Application of stabiliser is assumed to be by mixing into water and spraying the solution across the layer. Where two stabilisers are required, it is assumed that they can be mixed in the water tank and do not have to be applied separately.

Spreading cost:

Machine intensive:

R1.00 (low) to R2.00 (high) per m^3 of soil.

Labour intensive:

Need one extra man to measure off concentrate at say 13 doses per day (2 doses per hour for 6.5 hours, based on refilling and spreading 2 drums of 200 litres of water per hour: personal experience on Mamelodi Pilot Project) Each dose is assumed to be sufficient for 5 m^3 of soil, giving 13 x 5 = 65 m^3/day. Wage rate and total cost per man per day as before: R26.50 (low) to R43.00 (high), which gives spreading cost of R0.41 to R0.66 per m^3.

Conservex is an exception - this is applied to the top 50 mm layer in a separate application and hence should be costed separately.

The AECI Ababond (lignosulphonate) system is another exception in which Modlig is applied to the surface after the Lignos has been mixed into the top 50 to 70 mm of the wearing course.

TABLE A2.1 COST ESTIMATES OF APPLYING STABILISERS

Stabiliser	Application rate	Purchase cost	Spread cost/cu.m		Total cost/cu.m	
			Machine based	Labour based	Machine based	Labour based
Cement (OPC)	70 kg/cu.m	R14.00/50 kg =R19.60/cu.m	R2.00 to R5.00	R13.59 to R22.05	R21.60 to R24.60	R33.19 to R41.65
Lime (Stablim)	70 kg/cu.m	R12.00/25 kg =R33.60/cu.m	R3.00 to R7.00	R13.59 to R22.05	R35.60 to R40.60	R47.19 to R55.65
Conaid	200ml/cu.m	R5960/200 l =R5.96/cu.m	R1.00 to R2.00	R0.41 to R0.66	R6.96 to R7.96	R6.37 to R6.62
Roadamine	200ml/cu.m	R14.50/litre =R2.90/cu.m	R1.00 to R2.00	R0.41 to R0.66	R3.90 to R4.90	R3.31 to R3.56
Roadbond	200ml/cu.m	R4240/200 l =R4.24/cu.m	R1.00 to R2.00	R0.41 to R0.66	R5.24 to R6.24	R4.65 to R4.90
Roadbind no 1	800ml/cu.m	R7.50/l =R6.00/cu.m	R1.00 to R2.00	R0.41 to R0.66	R10.00 to R11.00	R9.41 to R9.66
Roadbind no 2 (these are mixed togethr in water tank	400ml/cu.m	R7.50/l =R3.00/cu.m				
		Total R9.00				
Consolid 444	400 to 800 ml/cu.m	R2275/200 l =R4.55 to R9.10/c.m	R1.00 to R2.00	R0.41 to R0.66	R5.55 to R11.10	R4.96 to R9.76
Conservex	10 to 20 l/m3 in 50 mm layer (=3 to 7 l/m3 in 150 mm layer)	R940/200 l =R14.10 to R32.90/m3	R1.00 to R2.00	R0.41 to R0.66	R15.10 to R34.90	R14.51 to R33.56
			Total Consolid System		R20.65 to R46.00	R19.47 to R43.32
Lignos	0.8 kg/sq.m per 150 mm layer	R1470/tonne = R7.84/cu.m	R1.00 to R2.00	R0.41 to R0.66	R8.84 to R9.84	R8.25 to R8.50
Modlig	0.4 kg/sq.m per 150 mm layer	R1600/tonne = R4.27/cu.m	R1.00 to R2.00	R0.41 to R0.66	R5.27 to R6.27	R4.68 to R4.93
			Total AECI Ababond System		R14.11 to R16.11	R12.93 to R13.43

APPENDIX 3

SPECIFICATIONS

**VARIATIONS AND ADDITIONS TO SABS 1200 DM - EARTHWORKS (ROADS,
SUBGRADE) FOR LABOUR INTENSIVE CONSTRUCTION OF LIGHTLY TRAFFICKED
ROADS USING CHEMICAL STABILISERS.**

NOTE: The numbering of the clauses follows the numbering of SABS 1200 DM.

VA-DM 3 MATERIALS

VA-DM 3.1 CLASSIFICATION FOR EXCAVATION PURPOSES

Delete this clause entirely and replace with:

Excavation will be classified for payment as follows:

VA-DM 3.1.1 Soft

Soft material shall be loose soil which can be efficiently excavated with a flat spade not exceeding 250 mm in width.

VA-DM 3.1.2 Firm

Firm material shall b.. soil which can be efficiently loosened with a fork or a forked hoe.

VA-DM 3.1.3 Hard

Hard material shall be soil which can only be loosened with many blows of a sharp pickaxe or mattock.

VA-DM 3.1.4 Soft Rock

Soft rock shall be material which is too hard to pick loose by hand and requires pneumatic tools to loosen it sufficiently for subsequent excavation with hand tools.

VA-DM 3.1.5 Hard Rock

Hard rock shall be rock which cannot be efficiently loosened with pneumatic tools and normally requires blasting.

VA-DM 3.1.6 Boulders

Boulders shall be hard rocks over 0.01 cubic metre and up to 0.20 cubic metre in volume. Larger boulders shall be classified as hard rock.

VA-DM 3.2 CLASSIFICATION FOR PLACING PURPOSES

VA-DM 3.2.3 Selected layer

c) 1) and 2) Delete from both clauses the words: "for natural material and 30 for stabilised material"

d) Change the value of the plasticity index to 25.
Add new clause:
e) at least 20% passing the 0.075 mm sieve.

Add new clause:

VA-DM 3.4 STABILISERS

VA-DM 3.4.1 Prescribed product
Where a particular product is prescribed, only this product shall be used. Should the Contractor wish to offer an alternative, the provisions of clause 3.4.2 shall apply.

VA-DM 3.4.2 Proposed by Contractor
The stabiliser that the Contractor proposes to use shall be a liquid ion-exchange type of chemical stabiliser. The suitability of the stabiliser shall be proved to the Engineer by means of standard soaked CBR tests performed on samples of all the soils which are to be stabilised. The CBR results shall equal or exceed the values laid down for the layer in which the material is to be used.

VA-DM 4 PLANT
Add new clause:

VA-DM 4.2 LIMITATIONS ON USE OF PLANT

VA-DM 4.2.1 Excavation
As the project is contractually required to be labour based, the only excavation equipment allowed will be (an) air compressor(s) and appropriate hand held pneumatic tools.

VA-DM 4.2.2 Transport of excavated materials
For hauls up to 200 m wheelbarrows shall be used. For hauls over 200 m, mechanical equipment is permitted with the stipulation that it shall be hand loaded. Off-loading may be by mechanical means.

VA-DM 4.2.3 Compaction
No limitations are placed on the Contractor in his choice of compaction equipment.

VA-DM 5 CONSTRUCTION

VA-DM 5.1 PRECAUTIONS

VA-DM 5.1.1 Safety, existing services, stormwater, etc and nuisance

Change the requirements for barricading to a barrier or fence of height at least 1 200 mm, sufficiently strong to contain pedestrians and prevent them from falling into the excavations at times when visibilty is low.

VA-DM 5.2 METHODS AND PROCEDURES

In general the words 'rip', 'ripped' or 'scarified' shall be taken to mean "loosened" and the words 'blade', 'blading' or 'bladed' shall be taken to mean "removed" or "smoothed" as the text requires.

VA-DM 5.2.7 Stabilisation

Delete and replace with:

The layerwork scheduled to be stabilised shall be placed and roughly shaped. The material shall be loosened where needed to the full depth of the layer.

The moisture content of the soil shall be measured and a calculation made of the quantity of water to be added to bring the soil to about 2% wet of the laboratory OMC. The number of tanks or bowsers required to apply this quantity of water shall be calculated.

The surface area of the section to be stabilised shall be calculated. The amount of stabiliser concentrate shall be calculated on the basis of applying 20 ml/sq.m for a 100 mm layer or 30 ml/sq.m for a 150 mm layer. The total volume of stabiliser shall then be divded over the number of tanks of water or water bowsers needed. The dilution of the stabiliser shall be calculated and recorded. The stabiliser shall be applied at dilutions in the range of 1:200 to 1:1000.

No stabilisers shall be applied when rain is falling or is imminent.

The water containing the stabiliser shall be applied uniformly across the full width and length of the section. The soil shall be mixed by turning over once with spades or shovels and shall then be left to soak up the water and chemicals for at least 2 hours, although overnight soaking is preferred.

At the end of the soaking period, the soil shall be thoroughly mixed by turning over at least twice with spades or shovels. The layer shall then be carefully shaped to the specified shape and level. After shaping, the layer shall be lightly rolled with one pass of a roller and reshaped. All bumps and hollows shall be taken out and large stones removed or broken down. Once smooth, the layer shall be fully compacted. The roller chosen shall be matched to the soil type and density requirement.

After compaction the layer shall be kept damp for at least three days either by frequent watering or by placing damp soil for the next layer over it.

Construction equipment should be encouraged to drive over the stabilised layer during the curing period.

VA-DM 6 TOLERANCES

VA-DM 6.2 DIMENSIONS, LEVELS, ETC.

VA-DM 6.2.1 General
To this clause add:

Degree of Accuracy III shall apply.

Add the values of permissible deviations for Degree of Accuracy III as follows:

VA-DM 6.2.2 Cut

c) Width of cut		
1) in cuttings other than rock cuttings	-0	+100
2) in rock cuttings	-0	+500

VA-DM 6.3 SELECTED LAYER

a) Formation level	+0	-60
b) Thickness	-20	+10

VA-DM 6.4 GRAVEL SURFACE LAYER

a) Finished surface level	+40	-40
b) Thickness	-10	+25

VA-DM 7 TESTING

VA-DM 7.3 ROUTINE INSPECTION AND TESTING

Add new clause:

VA-DM 7.3.3 Field density control

Density control shall be either by the sand replacement method or by an approved nuclear density meter. To obtain approval of the nuclear density meter, the Contractor will be required to provide a certificate from the supplier of the machine stating that the machine is in good working order. The machine must be properly and regularly calibrated and the results correlated with sand replacement tests on a fortnightly basis.

Sand replacement density test holes must be backfilled with material treated with the stabiliser (in stabilised layers) and properly compacted with hand rammers.

VA-DM 8 MEASUREMENT AND PAYMENT

VA-DM 8.3 SCHEDULED ITEMS

VA-DM 8.3.5 Selected layer compacted to 93% of Mod.AASHTO maximum density

Delete and replace with:

a) Excavate in road prism in soft material and trim to required profile...... Unit: cubic metre.
b) Excavate in borrow in soft material. ....Unit: cubic metre.
c) Excavate in stockpile.......Unit: cubic metre.

The rate shall cover the cost of complying with the precautions required in clause 5.1, selection, loading, transporting within the freehaul distance, offloading, spreading, watering, shaping, compacting and complying with tolerances.

VA-DM 8.3.6 Extra-over items 8.3.4 and 8.3.5 for excavating and breaking down material in:

Delete items a) to d) and replace with:

a) Firm	Unit: cubic metre
b) Hard	Unit: cubic metre
c) Soft rock	Unit: cubic metre
d) Hard rock	Unit: cubic metre
e) Boulders	Unit: cubic metre

VA-DM 8.3.7 Cut to spoil or stockpile from:

Delete items a) to e) and replace with:

a) Soft	Unit: cubic metre
b) Firm	Unit: cubic metre
c) Hard	Unit: cubic metre

d) Soft rock — Unit: cubic metre
e) Hard rock — Unit: cubic metre
f) Boulders — Unit: cubic metre

Add:

Cut to spoil and cut to stockpile will be scheduled separately.

VA-DM 8.3.8 Removal of oversize material
Delete this clause.

VA-DM 8.3.9 Overbreak of excavation in:
Delete items a) to d) and replace with:

a) Soft rock — Unit: square metre
b) hard rock — Unit: square metre
c) Boulders — Unit: square metre

VA-DM 8.3.12 Overhaul
Delete and replace with:

The rates shall cover the cost of transporting materials beyond the freehaul distance as follows:
a) Over 100 m up to 200 m — Unit: cubic metre
b) Over 200 m — Unit: cubic metre km.

VA-DM 8.3.13 *Surface finishes*
a) Topsoiling — Unit: square metre
Delete and replace with:
The rate shall cover the costs of excavating from stockpiles formed in terms of 8.3.2a) and loading, hauling within the freehaul distance, offloading, spreading, lightly compacting and trimming to the specified levels. The final thickness shall be at least 75 mm.

PARTICULAR SPECIFICATION FOR MINOR ROADWORKS BUILT BY LABOUR INTENSIVE METHODS

INDEX

1. SCOPE

This specification covers the requirements for labour intensive construction of low traffic volume roads, using chemical stabilisers.

2. INTERPRETATIONS

2.1 APPLICATION

This specification contains clauses generally applicable to minor roadworks constructed by labour intensive means, under the overall supervision of a Project Manager assisted by a full-time site Supervisor. For more extensive work, SABS 1200 D, M and DM shall be used.

2.2 DEFINITIONS

2.2.1 **Backfill**

Soil or gravel placed and compacted in an excavation.

2.2.2 **Borrow**

Soil or gravel obtained from various sources such as borrow pits.

2.2.3 **Bush**

Woody vegetation with a girth not exceeding 250 mm.

2.2.4 **Fill/ filling**

Soil or gravel placed and compacted to raise the level of the road foundation.

2.2.5 **Girth**

The circumference of the trunk of a tree, measured one metre above ground level.

2.2.6 **Grubbing**

The digging out of roots.

2.2.7 **Overbreak**

Excavation in excess of the theoretical or directed profile.

2.2.8 **Soft soil**

Soils which can easily be shovelled.

2.2.9 **Soft vegetation**

Non-woody vegetation like grass and weeds.

2.2.10 **Spoil**

Unsuitable or excess soil removed to waste.

2.2.11 **Stony soil**

Soils where the presence of stones or rocks makes shovelling difficult.

2.3 ABBREVIATIONS

For this specification the following abbreviations apply and shall have the meanings given below:

Mod.AASHTO density: The maximum dry density obtained by performing test method A7 in TMH 1: Standard methods of testing road construction materials.

OMC: Optimum moisture content, as determined by performing test method A7, TMH 1.

PD: Permissible deviation

3. MATERIALS

3.1 CLASSIFICATION OF EXCAVATIONS

Excavation will be classified for payment as follows:

3.1.1 Loose

Loose material shall be soil which can be efficiently excavated with a flat spade not exceeding 250 mm in width.

3.1.2 Firm

Firm material shall be soil which can be efficiently loosened with a fork or a forked hoe.

3.1.3 Hard

Hard material shall be soil which can only be loosened with many blows of a sharp pickaxe or mattock.

3.1.4 Soft Rock

Soft rock shall be material which is too hard to pick loose by hand and requires pneumatic tools to loosen it sufficiently for subsequent excavation with hand tools.

3.1.5 Hard Rock

Hard rock shall be rock which cannot be efficiently loosened with pneumatic tools and normally requires blasting.

3.1.6 Boulders

Boulders shall be hard rocks over 0.01 cubic metre and up to 0.20 cubic metre in volume. Larger boulders shall be classified as hard rock.

3.1.7 Methods

The Contractor may use any method he chooses to excavate any class of material, but his chosen method of excavation shall not determine the classification of the excavation. The Project Manager will decide on the classification of the materials based on inspection and trials, if so ordered, with hand and pneumatic tools.

Should the material classification apparently change during the course of excavation, the Contractor shall immediately notify the Supervisor and request re-classification. Material already excavated will not be re-classified.

3.2 CLASSIFICATION FOR PLACING PURPOSES

3.2.1 Fill

Material for fill shall generally be unselected material obtained directly from excavations, provided it contains no roots, vegetation, rubbish or stones over 150 mm in size and can be placed without significant voids.

3.2.2 Select layer

Material in the selected layer shall contain no roots, vegetation, rubbish or stones larger than 100 mm, shall have a CBR of at least 15 at 93% Mod.AASHTO density or if sand, at 100% Mod.AASHTO density and a maximum plasticity index of 15 for unstabilised material.

If the selected layer is to be stabilised with chemical stabilisers, the maximum plasticity index shall be 25 and at least 20% of the material shall pass the 0.075 mm sieve.

3.2.3 Wearing course

Material used for a wearing course shall be gravel with a maximum stone size of 50 mm, a plasticity index of not less than 6 or more than 18 and a CBR of at least 45 at 95% Mod.AASHTO density.

If the wearing course is to be stabilised with chemical stabilisers, the maximum plasticity index shall be 25 and at least 20% of the material shall pass the 0.075 mm sieve.

3.3 STABILISERS

3.3.1 Prescribed product

Where a particular product is prescribed, only this product shall be used. Should the Contractor wish to offer an alternative, the provisions of clause 3.3.2 shall apply.

3.3.2 Proposed by Contractor

The stabiliser that the Contractor proposes to use shall be a water soluble ion exchange type of chemical stabiliser. The suitability of the stabiliser shall be proved to the

Project Manager by means of standard soaked CBR tests performed on samples of all the soils which are to be stabilised. The CBR results shall equal or exceed the values laid down for the layer in which the material is to be used.

4. CONTRACTOR'S EQUIPMENT

4.1 TOOLS AND EQUIPMENT

The Contractor shall provide sufficient tools and equipment of adequate quality and capacity to fulfil his obligations in terms of the Contract. All tools and equipment shall be kept in good working order.

4.2 LIMITATIONS ON USE OF PLANT

4.2.1 Excavation

As the project is contractually required to be labour based, the only excavation equipment allowed will be (an) air compressor(s) and appropriate hand held pneumatic tools.

4.2.2 Transport of excavated materials

For hauls of up to 200 m wheelbarrows shall be used. For hauls over 200 m, mechanical equipment is permitted with the stipulation that it shall be hand loaded. Off-loading may be by mechanical means.

4.2.3 Compaction

No limitations are placed on the Contractor in his choice of compaction equipment.

5. CONSTRUCTION

5.1 PRECAUTIONS

5.1.1 Safety

The Contractor shall comply fully with the requirements of the Occupational Safety and Health Act (Act 65 of 1993) at all times.

Excavations accessible to the public and excavations left open overnight shall be barricaded [illegible] of a barrier or fence of height at [illegible], sufficiently strong to contain [illegible] and to prevent them from falling [illegible] excavations at times when visibility is low

Should the depth of the excavation or the nature of the material be such that collapse of the ground can be expected, the Contractor shall notify the Supervisor and
i) erect suitable timbering to protect the sides, or
ii) shall reduce the slope of the sides of the excavation to a safe angle.

5.1.2 Existing structures and services

The Contractor shall take adequate precautions to ensure the safety of all known structures and services. He will be liable for the costs of repair if negligent.

5.1.3 Water

The earthworks shall be protected from damage due to either erosion or flooding by water.

Excavations shall be kept reasonably dry at all times. The Contractor shall repair, at his own expense, any damage to the Works that may arise as a result of the inadequacy of the protection provided by him.

5.1.4 Pollution

The Contractor shall take all reasonable measures to minimise dust, mud on nearby roads, pollution of streams and inconvenience to the public because of the construction of the Works.

5.2 CLEARING OF SITE

The site shall be cleared of vegetation, rocks and rubbish. Trees are only to be cut down on the express instructions of the Supervisor. Bush shall be cleared. Bush stumps, tree stumps and roots are to be removed to a depth of half a metre below ground level. The resulting holes shall be backfilled with soil.

Bush shall be classified as follows:

Light: up to 2 bushes per 100 m^2.
Medium: over 2 and up to 10 bushes per 100 m^2.
Dense: over 10 bushes per 100 m^2.

If specified, topsoil shall be stripped and stockpiled after the vegetation cover has been removed.

When required by the Supervisor, the soft vegetation is to be slashed to leave a stubble not more than 100 mm high. The vegetation and soil shall then be dug to 200 mm depth and stockpiled for later use.

5.3 SETTING OUT

The Contractor shall perform the detailed setting out of the Works from the basic pegs and reference points supplied by the Project Manager. The Project Manager's pegs shall be protected from damage during construction.

5.4 EXCAVATION

5.4.1 General

Cuttings shall be excavated to the dimensions and levels laid down in the drawings. Materials arising from cuttings shall be sorted and used or stockpiled for later use in the most suitable way.

5.4.2 Cut to spoil

Unsuitable material excavated from cuttings shall be dumped at locations chosen by the Supervisor. Spoil dumps shall be neatly trimmed and shaped.

5.4.3 Blasting

No blasting will be permitted on the site. Non explosive methods shall be used. Hard rock and large boulders shall be drilled at suitable spacing using hand held pneumatic tools and shall be split by means of suitable equipment or material. The Contractor is at liberty to split rock by means of fire to heat the rocks followed by rapid quenching with water.

5.4.4 Borrow pits

Designated borrow pits shall be cleared of vegetation. Trees shall be left standing. Topsoil and overburden shall be separately stockpiled. Selective excavation shall be used to ensure that the required materials are not contaminated with undesired materials. Access tracks leading from the borrow pit to the roadworks shall be constructed and maintained by the Contractor.

On completion, the sides of the borrow pit shall be flattened to slopes not steeper than 1:2. Overburden shall be spread across the borrow pit sides and bottom and then covered with topsoil. Access tracks shall be dug up.

Borrow pits shall be left in a safe condition so as not to be a danger to people or animals.

5.5 FILL

5.5.1 General

All soils placed into the roadworks shall comply with the materials specification for the layer into which the soil is placed.

Soils and gravels shall be placed in layers not more than 150 mm thickness when compacted. The amount of loose material shall be adjusted to give the correct final compacted layer thickness (see drawing). Each layer shall be shaped to the correct profile. The moisture content shall be adjusted to within 2% of OMC.

5.5.2 Compaction

The compaction requirements for the roadworks are as follows:

TABLE 1: SPECIFIED DENSITIES

Layer	Required density as %Mod.AASHTO density	
	Soils and gravels	Sand
Fill	90 %	100 %
Selected layer	93 %	100 %
Wearing course	95 %	Not suitable

Before compaction, the full width and depth of the layer shall be loosened and mixed to ensure uniformity of material and moisture.

The layer shall be carefully shaped and raked to the correct camber or slope and lightly rolled once. The layer shall then be reshaped, taking out all bumps and hollows. When smooth, the layer shall be fully compacted. The roller chosen shall be matched to the soil type and density requirement.

5.6 STABILISATION

The layerwork scheduled to be stabilised shall be placed and roughly shaped. The material shall be loosened where needed to the full depth of the layer.

The moisture content of the soil shall be measured and a calculation made of the quantity of water to be added to bring the soil to about 2% wet of the laboratory OMC. The number of tanks or bowsers required to apply this quantity of water shall be calculated.

The surface area of the section to be stabilised shall be calculated. The amount of stabiliser concentrate shall be calculated on the basis of applying 20 ml/sq.m for a 100 mm layer or 30 ml/sq.m for a 150 mm layer. The total volume of stabiliser shall then be divided over the number of tanks of water or water bowsers needed. The dilution of the stabiliser shall be calculated and recorded. The stabiliser shall be applied at dilutions in the range of 1:200 to 1:1000.

No stabilisers shall be applied when rain is falling or is imminent.

The water containing the stabiliser shall be applied uniformly across the full width and length of the section. The soil shall be mixed by turning over once with spades or shovels and shall then be left to soak up the water and chemicals for at least 2 hours, although overnight soaking is preferred.

At the end of the soaking period, the soil shall be thoroughly mixed by turning over at least twice with spades or shovels. The layer shall then be carefully shaped to the specified shape and level. The layer shall then be fully compacted.

After compaction the layer shall be kept damp for at least three days either by frequent watering or by placing damp soil for the next layer over it.

Construction equipment should be encouraged to drive over the stabilised layer during the curing period.

5.7 FINISHING

5.7.1 Final trimming

On completion of the earthworks, the side slopes and road reserve shall be trimmed and shaped to the required slopes and levels and compacted where required by the Supervisor. Tops and toes of slopes shall be neatly rounded to minimise erosion.

5.7.2 Topsoiling and grassing

Where specified, topsoil from the stockpiles shall be brought in and spread to 100 mm loose thickness. Where scheduled, fertilisers and/or compost shall be spread and mixed into the topsoil. Grass or other vegetation, as scheduled, shall be planted and maintained until established.

6. TOLERANCES

6.1 PERMISSIBLE DEVIATIONS

The work described in this specification shall be finished to Degree of Accuracy III.

	Permissible Deviation for Degree of Accuracy III	
Position of toe of cutting, measured from road centre:		
a) in rock	+ 500	- 0
b) other	+ 300	- 0
Position of shoulder break point, measured from road centre	+ 200	- 0
Thickness of layer:		
a) selected	+ 50	- 25
b) wearing course	+ 50	- 0
Final road level from level specified on drawings	+ 40	- 40

6.2 SMOOTENESS

Deviation between the wearing course and a two metre long straightedge shall not exceed:

a) when laid parallel to the road centre line, 15 mm

b) when laid at right angles to the road centre line, 20 mm.

7. TESTING

7.1 TRIAL HOLES

The Project Manager may require the Contractor to excavate holes to determine depths of borrow materials or other purposes. The Contractor shall provide labour and tools for the excavation and backfilling of the trial holes. Such operations will be paid in accordance with the Bills of Quantities.

7.2 PRODUCTION CONTROL

The Supervisor will carry out measurements and tests to ensure compliance of the materials and workmanship with the specifications. The Contractor shall make available such labour as may be required by the Supervisor to carry out the production control of the roadworks. Such assistance will be paid for in accordance with the Bill of Quantities.

Where checks reveal that the requirements of the specification are not met, the Contractor shall rectify the work so that it does comply. The costs of rectification shall be carried by the Contractor.

8 MEASUREMENT AND PAYMENT

8.1 MEASUREMENT

8.1.1 Except where earthworks are carried out to simple geometric shapes, the volumes of the materials shall be computed from cross-sections at suitable intervals by the method of average end areas.

8.1.2 Where the Project Manager considers this method of measurement to be impractical, the volume will be computed from the predetermined capacity of the wheelbarrows or trucks, each being loaded to capacity. The volume of material shall be taken as 70% of the capacity in the case of soils and gravels and 50% in the case of boulders and all materials arising from bush and tree clearing.

8.2 PAY ITEMS

CLEAR SITE

8.2.1 Clear soft vegetation and stockpile within 4 m.

....................Unit:m^2

The rate shall cover the costs of removing all soft vegetation by hoe or spade and stockpiling the vegetation within 4 m, for subsequent removal. The area cleared shall be measured.

8.2.2 Slash soft vegetation and remove topsoil and vegetation to 200 mm depth to stockpile within 4 m.

....................Unit:m^2

The rate shall cover the cost of cutting down all soft vegetation and digging up the vegetation together with soil in the categories loose and firm, to a depth of 200 mm and stockpiling within 4 m for subsequent removal The area cleared shall be measured.

8.2.3 Clear and grub bush

a) light ....Unit:m^2

b) medium ....Unit:m^2

c) dense ....Unit:m^2

The rate shall cover the costs of cutting down bush of girth up to 250 mm and grubbing up the roots to 0.5 m depth, cutting the debris to transportable lengths and stockpiling for subsequent removal. The area cleared shall be measured.

8.2.4 Clear and grub trees of girth:

a) over 250 mm up to 450 mm .....Unit: number

b) over 450 mm up to 750 mm .....Unit: number

c) over 750 mm up to 1.20 m .....Unit: number

d) over 1.20 m up to 1.80 m .....Unit: number

The rate shall cover the costs of cutting down trees and grubbing up the roots to 0.5 m depth, cutting the debris to transportable lengths and stockpiling for subsequent removal. The number of trunks at the level of girth measurement (one m above ground) shall be measured.

8.2.5 Clear loose surface rocks ....Unit:m^3

The rate shall cover the costs of gathering all loose surface rocks over 100 mm average diameter into stockpiles within 4 m for subsequent removal. The unit of measurement shall be 50% of the volume of the stockpile (see clause 8.1.2).

EXCAVATION

8.2.6 Excavate and throw material up to 4 m in:

a) loose material .....Unit: m^3
b) firm material .....Unit: m^3
c) hard material .....Unit: m^3
d) soft rock .....Unit: m^3
e) hard rock .....Unit: m^3
f) boulders .....Unit: m^3

The rates shall cover the costs of excavation in all materials, including the operation of tools and all equipment required. The cost of rough trimming shall be included. The volume measured shall be in cut ie. before loosening.

8.2.7 Trim to final level or slope in:

a) loose material .....Unit: m^2
b) firm material .....Unit: m^2
c) hard material .....Unit: m^2
d) soft rock .....Unit: m^2

The rates shall cover the costs of trimming in all materials scheduled to final shape, level and slope and spreading or stockpiling the materials arising. The area measured shall be the actual slope area trimmed.

TRANSPORTATION

8.2.8 Load onto trailer or truck:

a) Vegetation, bush, trees and roots ..Unit: m^3

b) Topsoil and vegetation mixed ....Unit: m^3

c) Surface rocks ......Unit: m^3

The rates shall cover the costs of loading all materials arising from site clearing separately onto trailers or flat-bed trucks. The unit of measurement shall be 50% of the capacity of the trailer or truck for a) and c) and 70% for b), as provided for in clause 8.1.2. The vehicles shall be loaded to full capacity.

8.2.9 Move loose materials up to 4 m:

a) soft soils .....Unit: m^3

b) stony soils .....Unit: m^3

The rate shall cover the costs of moving previously excavated soils into position or stockpile up to 4 m away. The soils shall be divided into soft soils which can easily be shovelled and stony soils where the presence of stones or rocks makes shovelling difficult. The measurement shall be the loose volume of soil moved.

8.2.10 Load trailers and trucks with:

a) soft soils .....Unit: m^3

b) stony soils .....Unit: m^3

c) boulders .....Unit: m^3

The rate shall cover the costs of loading all materials separately onto trailers or flat-bed trucks. The unit of measurement shall be 70% of the capacity of the trailer or truck for a) and b) and 50% for c), provided that the vehicles are loaded to full capacity.

8.2.11 Transport materials by:

a) trailer drawn by tractor ....Unit: m^3.km

b) flat-bed truck .....Unit: m^3.km

The rate shall cover the costs of operating the tractors, trailers and/or trucks required to transport materials on the site. The unit shall be the factored volume of the material carried on the vehicle multiplied by the length of the shortest practical route the material is to be hauled.

8.2.12 Unload trailers and trucks by hand ....Unit: m^3

The rate shall cover the costs of unloading all materials from the trailers or trucks by hand labour. The measurement shall be as items 8.2.8 or 8.2.10.

8.2.13 Load wheelbarrows, transport and tip all materials:

a) over 4 m up to 50 m .....Unit: m^3

b) over 50 m up to 100 m .....Unit: m^3

c) over 100 m up to 150 m .....Unit: m^3

d) over 150 m up to 200 m .....Unit: m^3

The rate shall cover the costs of loading all materials into wheelbarrows, transporting up to the distances scheduled and tipping the loads. The measurement shall be the struck volume of the wheelbarrow factored as required in clause 8.1.2. The wheelbarrows shall be loaded to capacity.

CONSTRUCTION

8.2.14 Spread and level:

a) soft soils .....Unit: m^3

b) stony soils .....Unit: m^3

The rate shall cover the costs of spreading and levelling previously thrown or tipped soils to the required levels and slopes. The volume measured shall be the final compacted volume of the layer.

8.2.15 Loosen in situ materials .....Unit: m^2

The rate shall cover the costs of loosening the in situ soils in firm and hard materials to a depth of 150 mm, measured in situ.

8.2.16 Supply and apply water .....Unit: kilolitre

The rate shall cover the cost of acquiring and transporting water for compaction to the site and applying it to each layer in the correct quantities.

8.2.17 Supply stabiliser ....Unit: litre or kilogramme

The rate shall cover the cost of supplying to the site the approved water soluble stabiliser, measuring off the correct dosage and mixing the stabiliser in the water needed for compaction. The unit measured shall be the actual amount used in stabilisation.

8.2.18 Mix soil

a) soft soil .....Unit: m^3

b) stony soil .....Unit: m^3

The rate shall cover the cost of mixing into the soil the water (and stabiliser if required) by turning over the soil at least three times (once after stabiliser application and twice after soaking) and raking to the correct shape and level. The volume measured shall be the final compacted volume of the layer.

8.2.19 Trim and level during compaction .....Unit: m^2
The rate shall cover the cost of trimming and levelling in all materials during compaction, to achieve the required shape and slope, irrespective of how many times the surface has to be reshaped.

The area measured shall be the surface area of the layer trimmed.

8.2.20 Compact to specified percentage of Mod.AASHTO density:

a) 90% .....Unit: m^3
b) 93% .....Unit: m^3
c) 95% .....Unit: m^3
d) 100% (for sand) .....Unit: m^3

The rate shall cover the cost of compacting the layer to the specified density by what ever roller or combination of rollers is necessary. The rate shall include the operating costs of the rollers. The volume measured shall be the final compacted volume of the layer.

8.2.21 Maintain access tracks .....Unit: m^2/day
The rate shall cover the costs of maintaining the access tracks on site for every day the track is in use. The surface area of the track shall be measured and the rate shall be paid for every day the track is actually used.

8.2.22 Grassing .....Unit: m^2

The rate shall cover the cost of supplying suitable grass sprigs, planting, weeding and cutting the grass until properly established. Watering will be paid for under item 8.2.15.

MISCELLANEOUS

8.2.23 Erect and maintain barricades .....Unit: m

The rate shall cover the costs of supplying, erecting and maintaining suitable barricades in the positions ordered and their subsequent removal when no longer required. The length of the barricade shall be measured.

8.2.24 Provide labour to Supervisor ....Unit: man-day

The rate shall cover the cost of providing the Supervisor with labour when requested for setting out, checking, testing, measuring, etc.

8.2.25 Provide tools and equipment:

a) hand tools .....Unit: sum
b) pneumatic tools .....Unit: sum
c) compressor (..m^3 at ..bar) .....Unit: sum
d) rock-splitting equipment .....Unit: sum
e) roller (size .....) .....Unit: sum
f) flat-bed truck (size .....) .....Unit: sum
g) trailer (size ......) .....Unit: sum
h) tractor .....Unit: sum
i) ....Unit: sum

The rates shall cover the costs of supplying all needed hand tools, equipment and plant and the costs of removal when the project is complete. Half of the payment for each item will be made at the end of the month during which the item was first brought to site and half when the item is taken away.

8.2.26 Maintain tools and equipment.

a) hand tools .....Unit: sum/month
b) pneumatic tools .....Unit: sum/month
c) compressor (..m^3 at ..bar)...Unit: sum/month
d) rock-splitting equipment ....Unit: sum/month
e) roller (size .....) .....Unit: sum/month
f) flat-bed truck (size ....)...Unit: sum/month
g) trailer (size ......) ....Unit: sum/month
h) tractor ....Unit: sum/month
i) ....Unit: sum/month

The rates shall cover the costs of maintaining all needed tools, equipment and plant per month the equipment is on site.

8.2.27 Provide, maintain and remove tool sheds ....Unit: sum

The rate shall cover the costs of providing, maintaining and removal when no longer required, as many tool sheds as are needed on the site to store all tools, equipment, oil and materials.

ACKNOWLEDGEMENT

ACKNOWLEDGEMENT IS MADE TO THE SOUTH AFRICAN BUREAU OF STANDARDS FOR EXTRACTS FROM SABS 1200: STANDARDISED SPECIFICATIONS FOR CIVIL ENGINEERING CONSTRUCTION

APPENDIX 4

PROCEDURE FOR ROADAMINE APPLICATION

1. LABORATORY TESTING

X-ray diffraction
Indicators: MODS, P.I., L.S., Swell., OMC,
Dilution rates, upper 1 - 500 lower 1 - 150

2. PREPARATION OF SURFACE

a) Remove vegetation and root systems
b) Remove top soil if necessary
c) Cut drains, shape the road to lines and levels as required
d) Check insitu moisture

3. CHEMICAL PREPARATION

a) From O.M.C. and insitu moisture work out quantity of water required, then add 1 - 3% depending on weather conditions.
b) From square meters to be prepared for the day work out chemical required at ± 0.03ℓ/m² or as recommended.
c) Divide the capacity of the watercart into the required amount of water giving the number of loads and in turn the amount of Roadamine per load.
d) Mixing is done by either circulation or by the watercart travelling to sites.
e) Add the Roadamine to the full water cart.

4. PROCESSING

Spray the solution to the surface layer which is either the existing road or cut or fill.
Scarify to a depth of 150mm and apply solution continuously whilst processing to break down large conglomerates of material. If applicable the insitu material should be stabilised before imported material is placed and stabilised. All stone and other solid materia' larger than normal size of 100mm shall be removed from the surface layer.

TAKE CARE TO:

a) Only apply the solutions to within the limits of the surface to be treated.
b) Avoid subsequent applications of solution over lapping.
c) Mix the solution thoroughly into the surface layer with a disc, plough, grader or rotovator.

After all the Roadamine solution has been applied, the material should be close to O.M.C. The material shall be mixed until homogenous and the watering shall continue until the approved moisture has been obtained.

5. COMPACTION

Compaction may commence at O.M.C. or slightly above using conventional compaction equipment. Water shall be added from time to time to supplement any losses due to evaporation if necessary. Compaction shall be carried out until the specified density is obtained i.e. min 96%

After compaction the road or area may be opened for access. Any deformation should be corrected by grading before the material dries out.

2/...

CURING

Curing is done over a 3 to 5 day period by adding pure water.

PROCESSING DURING RAINY WEATHER

If the material becomes excessively wet because of rain after Roadamine has been applied, cease operations and allow the material to dry out or dry by mixing. The compaction may recommence once the material has dried sufficiently. This is possible because there is no time period.

AREAS INACCESSIBLE BY WATER CART

Areas which cannot be wetted by water cart can be sprayed by hand using a hose. The Roadamine shall be mixed to the same ratio applicable to spraying by water cart.

SURFACING

Surfacing should not take place until a minimum density of 98% has been reached or the moisture has reduced by at least 35 - 40%. A crocodile cracking pattern will appear, then surfacing can take place.

PROCEDURE

Wet the surface slightly and broom the surface dust off the road.
Spray 1 - 1.2 litres/m² of MC3000 for a sand seal. We have found no rejection of cationic or anionic bitumens with Roadamine

APPENDIX 5

SLURRY SEAL

A slurry seal is a dense, bitumen rich, asphalt layer used both in new construction and in maintenance as a finishing layer to a road. The surface texture is dependent on the aggregate size, but is generally fairly smooth and is pleasant to walk upon.

Slurry is applied in a liquid form, comprising crusher dust (usually -6 mm, but coarser if desired), stable grade bitumen emulsion, cement or lime filler (<2%) and water. The slurry must be properly mixed and is then spread across the road surface with hand squeegees, to fill the voids and hollows in the surface. The drying time is dependent on the air temperature and on the type of emulsion used. No traffic of any description should be permitted on the slurry while it is wet as indelible tracks will be left. The slurry surface is best rolled with a pneumatic roller immediately after it is dry, but this can often be left to the traffic.

The residual bitumen content of the slurry should be between 8% and 12% by mass of aggregate, depending upon the density of traffic expected. Thick slurries can be made from coarse crusher dust (-10 mm), if a thicker surface is required, but these **must** be rolled after drying. Sometimes a double slurr, ayer is desirable, as in the case of a cape seal with a 19 mm stone seal. Here the first slurry layer should be more liquid than the second, to fill all the voids in the stone layer. (Draft TRH 3, 1986).

APPENDIX 6

TECHNIKON COURSE FOR ROAD BUILDERS - 1993

This course was especially compiled for the Mamelodi Road Builders by the Pretoria Technikon and is on a par with other short courses offered by the Technikon. The syllabus and contents list are given here, together with brief comments on the course content.

SHORT COURSE ROAD BUILDING: FOREMAN MAY/JUNE 1993			
DATE	TIME	LECTURER	SUBJECT
MONDAY 17 MAY	09:30	Technikon Pretoria: Wynand van Wyngaard	Soils
TUESDAY 1 JUNE	09:30	Technikon Pretoria: Wynand van Wyngaard	Soils
WEDNESDAY 2 JUNE	09:30	Technikon Pretoria: Wynand van Wyngaard	Overlays
THURSDAY 3 JUNE	09:30	Technikon Pretoria: Wynand van Wyngaard	Overlays
MONDAY 7 JUNE	09:30	Technikon Pretoria: Wynand van Wyngaard	Concrete
TUESDAY 8 JUNE	09:30	Technikon Pretoria: Wynand van Wyngaard	Concrete
MONDAY 14 JUNE	09:30	Technikon Pretoria: Wynand van Wyngaard	Construction
TUESDAY 15 JUNE	09:30	Technikon Pretoria: Wynand van Wyngaard	Construction
THURSDAY 17 JUNE	09:30	Technikon Pretoria: Jack Bisschoff	Survey
FRIDAY 18 JUNE	09:30	Technikon Pretoria: Jack Bisschoff	Survey
MONDAY 21 JUNE	09:30	Technikon Pretoria: Wynand van Wyngaard	Management
TUESDAY 22 JUNE	09:30	Technikon Pretoria: Wynand van Wyngaard	Management

SYLLABUS

SOILS:

Definition

Problem soils

Clay

Collapsing soils

Sand

Swamps

Atterberg limits

Grain distribution

Maximum dry density and optimum moisture

CBR

UCS

In-place density

OVERLAYS:

Binders for overlays

Introduction to overlays

Construction of overlays

CONCRETE

Cement

Mix

Transportation

Placing

Curing

Mix design

CONSTRUCTION

Road building machine

Construction of cut and fills

Construction of pavement layers

Construction of surface and subsurface drainage

Stabilisation

Slope protection

SURVEY

Tape:

3:4:5 rule

Setting out curve

Base line, offsets, intersection

Levels:

Slopes

Extend heights

Profile

Profile planks

Levelling read staff

Levelling setting out

Levelling heights

Plans:

Plan

Ranging rods straight line

MANAGEMENT

General management

Planning of project

Costs

Stock control

Road building and the environment

TECHNIKON PRETORIA

PROSPERITAS PER PERITIAM

TECHNIKON
SERTIFIKAAT CERTIFICATE

in

Uitgereik aan issued to

Opleidingstydperk Period of training

....
Direkteur/Director

....
Akademiese Skool/Academic School

....
Direkteur/Director
Akademiese Administrasie/Academic Administration

....
Uitreikingsdatum/Date of Issue

SOILS

This comprised a quick and basic theoretical course and was backed up by demonstrations and some hands on practise with laboratory equipment. The subject is so large that only a very brief introduction could be given in the time available.

OVERLAYS

A short introduction was given on bitumen surfacing seals, aided by laboratory work in building up a demonstration model of a double seal. The course was based on SABITA's manuals on "Labour enhanced construction for bituminous surfacings" and was therefore relevant to the Mamelodi project. Some information was supplied about bitumen and tar types in common use. Asphalt (or premix) was not covered at all.

CONCRETE

This comprised a level 1 course led by the Portland Cement Institute "Introduction to Concrete", which is an excellent basic course. No concrete work was done on the Mamelodi Pilot Project, but the course had great practical value for other projects.

CONSTRUCTION

These lectures comprised an introduction to conventional machine intensive road construction, methods and plant. Very little was relevant to the Mamelodi project, except the use of compaction plant. However, the exposure to conventional machine based methods could be compared and contrasted to the labour intensive approach taken at Mamelodi.

SURVEY

This comprised very basic measurement and setting out methods, use of profiles, use of a simple automatic level and staff and practise in all the above. The skills learned were relevant.

MANAGEMENT

An introduction to different management styles and objectives was given. The course was highly theoretical and the relevance to a labour based project is doubtful.

APPENDIX 7 STATISTICAL ANALYSIS

The Student "t" test was used to compare CBR strength tests using two hypotheses: a null hypothesis, meaning that the tests were from the same normal distribution; and an alternative hypothesis that the tests were significantly different.

Firstly the CBR tests on the natural soil were examined. Each test was compared with the next test to see if differing curing regimes made any real difference to the values measured.

TABLE A7.1 NATURAL SOIL: EACH TEST COMPARED TO NEXT TEST

Comparison between tests	t
Test 1 vs test 2	- 0.54
Test 2 vs test 3	1.62
Test 3 vs test 4	0.81
Test 4 vs test 5	1.44

The critical value of t for 2 degrees of freedom for a two sided test at 95% probability limits is 4.30. As all values of t calculated above lie within the range of + t_{crit} to - t_{crit}, the CBRs are from the same normally distributed population and the curing makes no significant difference.

Secondly, each test was compared with the remaining tests of the group of CBR measurements on the natural material.

TABLE A7.2 NATURAL SOIL: EACH TEST COMPARED TO GROUP

Comparison between tests	t
Test 1 vs tests 2 to 5	- 1.81
Test 2 vs tests 1, 3, 4, 5	- 0.73
Test 3 vs tests 1, 2, 4, 5	2.15
Test 4 vs tests 1, 2, 3, 5	0.98
Test 5 vs tests 1, 2, 3, 4	- 0.47

The critical value of t for 13 degrees of freedom for a two sided test at 95% probability limits is 2.16. As all values of t lie within the range of + t_{crit} to - t_{crit}, the CBRs are from the same normally distributed population and the curing makes no significant difference.

Having compared the tests on the natural material in two different ways and having obtained the same result, it can be confidently stated that the different curing regimes make no difference to the natural soil tests at the 95% probability level.

Then test results using stabiliser A were examined. Firstly each test was compared with the remaining tests of the group of CBR measurements on the stabilised material.

TABLE A7.3 STABILISER A: EACH TEST COMPARED TO GROUP

Comparison between tests	t
Test 1 vs tests 2 to 5	- 0.53
Test 2 vs tests 1, 3, 4, 5	5.86
Test 3 vs tests 1, 2, 4, 5	- 1.68
Test 4 vs tests 1, 2, 3, 5	- 1.17
Test 5 vs tests 1, 2, 3, 4	0.09

The critical value of t for 13 degrees of freedom for a two sided test at 95% probability limits is 2.16. As all values of t (except test 2) lie within the range of + t_{crit} to - t_{crit}, the CBRs are from the same normally distributed population and the curing makes no significant difference. Test 2, with t = 5.86, is outside the 95% probability limits and the result is significantly different, possibly due to the specific curing regime imposed on that test.

Secondly, each test using stabiliser A was compared with the group of natural test results, to see if the use of the stabiliser made any difference to the CBR strengths.

TABLE A7.4 STABILISER A: EACH TEST COMPARED TO NATURAL GROUP

Comparison between tests	t
Test A1 vs natural tests 1-5	9.99
Test A2 vs natural tests 1-5	17.11
Test A3 vs natural tests 1-5	20.72
Test A4 vs natural tests 1-5	6.35
Test A5 vs natural tests 1-5	-12.49

The critical value of t for 16 degrees of freedom for a two sided test at 95% probability limits is 2.12. As all values of t lie outside the range of + t_{crit} to - t_{crit}, the CBRs are not from the same normally distributed population and the stabiliser improves the CBR strengths significantly. For a one sided test at the 95% confidence limit, the critical value of t is 1.75 and the values calculated above lie even further outside the critical range. Thus all the tests on soil treated with stabiliser A do not form part of the natural soil test population, at 95% confidence limits.

Then test results using stabiliser B were examined. Firstly each test was compared with the remaining tests of the group of CBR measurements on the stabilised material.

TABLE A7.5 STABILISER B: EACH TEST COMPARED TO GROUP

Comparison between tests	t
Test 1 vs tests 2 to 5	1.31
Test 2 vs tests 1, 3, 4, 5	- 2.74
Test 3 vs tests 1, 2, 4, 5	0.49
Test 4 vs tests 1, 2, 3, 5	- 1.47
Test 5 vs tests 1, 2, 3, 4	2.11

The critical value of t for 13 degrees of freedom for a two sided test at 95% probability limits is 2.16. As all values of t (except test 2) are within the range + t_{crit} to - t_{crit}, the CBRs are from the same normally distributed population and the curing makes no significant difference. Test 2, with t = -2.74 is outside the 95% probability limits and the result is significantly different (lower in this case), possibly due to the specific curing regime imposed on that test.

Secondly, each test using stabiliser B was compared with the group of natural test results, to see if the use of the stabiliser made any difference to the CBR strengths.

TABLE A7.6 STABILISER B: EACH TEST COMPARED TO NATURAL GROUP

Comparison between tests	t
Test B1 vs natural tests 1-5	10.62
Test B2 vs natural tests 1-5	2.11
Test B3 vs natural tests 1-5	7.51
Test B4 vs natural tests 1-5	4.36
Test B5 vs natural tests 1-5	11.47

The critical value of t for 16 degrees of freedom for a two sided test at 95% probability limits is 2.12. As all values of t (except test 2) lie outside the range of + t_{crit} to - t_{crit}, the CBRs are not from the same normally distributed population and the stabiliser improves the CBR strengths significantly. Test 2 with t = 2.11 lies within the 95% confidence limits of the natural soil test population and is thus statistically indistinguishable from the natural tests.