STOCKPILE LIFE OF FOAM STABILISED MATERIAL AND THE IMPLICATIONS FOR LABOUR INTENSIVE CONSTRUCTION.

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DECLARATION

I declare that this thesis is my own, unaided work . It is being submitted for the 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.

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ABSTRACT

Various studies have been done to show that labour-based construction can meet the high standards normally required in the construction of roads. The organisational requirements that were needed to ensure the efficient use of labour have also been dealt with in various studies. The need for alleviation of poverty, unemployment and the negative social impact thereof by increasing the labour input in construction is understood by all concerned.

A further step is however necessary before the idea of increasing the labour component in any kind of roadwork can be taken seriously. Engineers need to move forward from the policy and organisational issues associated with labour intensive construction and start to provide designers with sound and innovative engineering solutions to overcome the hurdles experienced on the ground.

This study looks at the process of foam bitumen stabilisation of soils and gravels with a view of utilising this innovative method for labour intensive construction. The material after having been stabilised can be placed in a stockpile. Actual durations that the material can safely remain in stockpile have been determined in this study to be in excess of six months for recycled asphalt and in excess of four months for the foam stabilised sand. Foam stabilised gravel was also studied and showed that after a year in stockpile the material failed probably due to a weakening of the bitumen and aggregate bond. Covering the stockpiled material did not show any significant difference to that of a similar uncovered stockpile. The position within the stockpile also did not have much effect on the engineering properties of the stoc piled material.

The fact that the foam stabilised material can be worked on when cold and that it can be stockpiled for several months implies that the material is labour friendly and can be used in labour intensive construction of road base course layers or wearing course layers.

Dedication

I would like to dedicate this project to the my father (Ruvimbo) , mother (Mildred) and wife (Martha) without whose love and care I would not have been able to undertake this programme.

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1.0 Introduction

1.1 The Purpose of the Study

The purpose of this study is to ascertain the properties of foamed bitumen treated soils and gravels as far as stockpiling and curing conditions are concerned. Foamed bitumen has in the recent past emerged as a stabiliser that has great potential in the application of labour intensive construction. This application is due to two main properties of foamed bitumen:

- Foamed bitumen treated soils and gravels can be worked while cold which makes it amenable to labour intensive construction methods.

- Foamed bitumen can be used to improve marginal road construction materials to acceptable base course standards while keeping the material workable.

  Some methods that are used to stabilise available materials include cement and lime stabilisation and bitumen emulsion treatment. Foam stabilisation has recently emerged as a feasible and innovative method of stabilisation with the possibility of increasing the labour content without sacrificing quality. The length of time during which a material can be worked is critical. A material that hardens over a short period of time (for example a few hours) does not lend itself to the use of labour intensive methods as it would necessarily hurry the construction rate and could lead to compromises on the quality of the work. On the other hand a material that has a significant period over which it retains its properties would afford the workmen the opportunity of organising their work processes to suit the required specifications and would ultimately result in a quality commodity. Foam stabilised material has this potential and hence this study intends to determine the duration which the foam stabilised material can be stockpiled.

The purpose of this study was to determine the following:

- The duration to which foamed materials, foamed sand, foamed gravel and foamed reclaimed asphalt (RAP), could be stockpiled and yet still retain their physical properties or usefulness in engineering terms.

- To determine the effect, on the physical properties, of covering the foam bitumen stabilised stockpile material and protecting it against adverse conditions such s. nlight and rain.

- To determine the effect, on the physical properties, of the relative position of materials in the stockpile and to determine the variation of deterioration within the stockpile.

- To ascertain the curing conditions required for optimum results.

The properties that are currently used in South Africa in the design of the foam bitumen stabilised materials are the following:[1]

a) The dry and wet Marshall stability or the dry and wet Indirect Tensile Strength (ITS)

b) The retained Marshall stability or the retained ITS.

c) Resilient modulus at 25 °C.

d) Dynamic creep at 25 °C.

These parameters were used in this study to determine the various properties of the foam stabilised material in the stockpiles.

1.2 Implications of Labour Intensive Construction

1.2.1 Unemployment

Unemployment is the main cause of adverse social behaviours in societies where it soars to high levels. This is the situation in many countries of the world especially the so called third world countries of which South Africa is not exempted. This situation has prompted the government of South Africa to come up with such programmes as the Reconstruction and Development Programme (RDP) to counter the trend of the world towards such niceties as computerisation and automation which tend to negatively impact on the unemployment situation. The various organisations and institutions that have the capacity to address poverty and sustained job creation should have a clear philosophical approach to labour intensive construction (Horak et al 1995).

1.2.2 Related Studies

A number of studies have been done to determine whether the trend towards mechanisation can be reversed by introducing labour to do the same work, and one such study done by the World Bank in 1971 concluded that; "It is technically possible to substitute labour for equipment for all but about 10 to 20% of the total road construction costs for the higher quality construction standards considered here, while relaxation of standards to an intermediate quality permits labour substitution for an additional 5 to 6 % of the costs" (IBRD report,1971). The above having been accepted in theory, was proved in practise by projects that were done in Africa by Prof. R. McCutcheon(McCutcheon, 1990). The best known of the projects is the Kenyan Rural Access Road Project (McCutcheon, 1993). The philosophy of the substitution of labour for equipment becomes easier to grasp when it is realised that all the first stone base pavements were constructed by human power in the first wave of the human development (Horak et al, 1996). Using labour intensive construction methods, the Romans were able to construct 33 000km of road (Steiger, 1993).

An important factor in the continued use of labour based road construction was the continued improvement of the road building material. The road materials developed from the Roman type stone roads to more uniform stones laid edgewise developed by Pierre-Marie Jerome Tresaguet (Steiger, 1993). In the eighteenth century Thomas Telford improved the road construction materials by using smaller rocks (75mm thick, 125mm wide and 325mm deep) and John Louden Macadam subsequently developed the material by using 25mm diameter aggregate (Steiger, 1993). The highly labour intensive waterbound Macadam roads are still in use today even in South Africa (Horak, 1983).

A lot of work has been done in relation to the use of labour intensive road construction in rural areas in Africa (McCutcheon, 1990 and 1993) and in the urban areas (Gertzen, 1996). All these previous studies show that labour intensive construction is a feasible construction method. Emphasis should be placed on technical aspects to bolster the developments in labour intensive construction. Some of the work done includes the engineering of the material properties to make them labour friendly and the introduction of innovative methods of construction (SABITA, 1994 and Weinmann, 1996). This document also intends to contribute towards the search for labour friendly materials and procedures that will ultimately result in a greater labour component in road construction.

2.0 AN INTRODUCTION TO FOAM BITUMEN STABILISATION

2.1 SCOPE

This chapter covers foamed bitumen, its history, properties and how it is used to stabilise soils and gravels. Particular attention is drawn to the labour friendly aspects of this product.

2.2 DEFINITIONS

Bitumen : Bitumen is a dark brown to black cementious material formed from surface accumulation of petroleum or may be found naturally impregnated within porous rock such as sandstone or limestone as rock bitumen. Modern bitumen is produced commercially by refining crude oil.

Stabilisation : Stabilisation is any process whereby the properties of a material are improved (Transvaal Roads, 1973). Types of stabilisation methods include:

- Cement stabilisation
- Lime stabilisation
- Emulsion stabilisation
- Foam stabilisation

Aggregate :This is the solid material that makes up the matrix of road construction materials and includes gravels, sand and weathered rock material.

Foamed Bitumen: This is a binder agent produced by the injection of 1.5-2.5% cold water into a hot penetration grade bitumen. This results in a significant increase in the bitumen volume and a decrease in the viscosity of the bitumen. The change in viscosity allows for ease of mixing with damp or wet aggregate.

Foam Stabilised Material: Refers to aggregate material that has been mixed with foamed bitumen in order to improve the properties of the aggregate to suit the required road requirements.

In this study the following terms are used to describe different types of materials that have been stabilised with foamed bitumen:

- Foam stabilised Sand for a mixture of foamed bitumen and sandy aggregate.
- Foam stabilised Gravel for a mixture of gravel and foamed bitumen.
- Foam stabilised RAP material for a mixture of reclaimed asphalt and foamed bitumen.

2.3 DESCRIPTION

Foam bitumen is bitumen that has been mixed with moisture in order to engineer the properties of the bitumen. The most important physical properties of a bituminous binder are its viscosity and its surface tension. These two parameters are of great importance when considering bituminous paving mixtures. In the making of bituminous mixes, the binder must be fluid enough to flow through the entire aggregate mass and coat this aggregate wholly. While in the laying, the mixture should remain plastic enough to be spread easily. It is then important that the spread material should harden quickly thereafter to allow the passage of vehicular traffic.

The surface tension is important as far as the bonding of the binder to the aggregate is concerned. Surface tension of the binder in relation to that of the aggregate must be such that the surface moisture of the aggregate can be displaced and a strong bond formed between the binder and the aggregate.

In our technology the required viscosity is normally obtained by heating the binder and to ensure proper bonding of the aggregate with the binder, the aggregate is usually heated. This is a costly exercise as the temperature of the binder has to be maintained at temperatures as high as 160-170°C for significant time durations. It suffices to say that these high temperatures ma n it .. ificult for human labour to work the mixture.

Other bituminous binders available are cutback bitumens and emulsified bitumens. The idea here is to decrease the viscosity of the binder and th .reby significantly reduce or eliminate the need to heat the binder or the aggregate. There are however problems of laying associated with the latter binders. The binder should set quickly after laying and this implies that the solvent in the cutbacks should be removed quickly and the emulsion should break at the proper time and water should be eliminated rapidly. This may necessitate the use of additional equipment and delay the opening of the road to traffic. The delay is undesirable.

Foamed bitumen approaches the ideal binder, i.e. one that can be used on cold or even damp aggregate and which retains sufficient plasticity to be spread easily and then sets quickly. The process of foaming has been shown not to affect the chemistry of the binder. If foamed bitumen is used in mixing aggregate and binder, the aggregate does not need to be heated and it has been shown that foamed bitumen penetrates crevices and does not only coat the agglomerations of dust as the liquid binders will do. Foam is also useful in that it is immediately effective and that it does not greatly alter the existing moisture content of the road in those cases where insitu stabilisation is used. The advantage of this is that the road can be opened to traffic directly. If emulsions are used the moisture content of the road is altered. In addition the emulsion can take a long time before it breaks and releases the bitumen. The increased moisture content and delayed binding action of the bitumen leads to the probability of problems such as rutting (Department of Transport, 1993).

2.4. PHYSICAL AND CHEMICAL ASPECTS OF FOAMED BITUMEN:

The process of foaming is an alternative method of reducing the viscosity of bitumen without the use of cutters or high water levels as in emulsions. The fineness of the bitumen created facilitates the coating of the aggregate surface. It has been found that the foam has the following properties (Macarone et al, 1993);

Table 2.4.1: Percentages of Constituent Elements in Foam Bitumen

	Bitumen	Water	Additives	Air
Before Foaming (By mass)	97%	2%	1%	-
After Foaming (By volume)	5%	-	-	95%

Water is lost by evaporation in the expanded state resulting in the changes shown in the table. The air escapes and the foam collapses to give a bitumen residue similar in properties to the original bitumen.

2.5 MATERIAL PARAMETERS AND DESIGN

The following material parameters were obtained from a " bituFOAM for Africa" pamphlet (Lewis, undated). The soil or gravel used for the base or wearing course should comply with the following:

Table 2.5.1 Aggregate Requirements for Foaming.

Maximum particle size	53mm
Grading modulus, minimum	1.8
Plasticity Index , maximum	10, unless treated with roadlime in which case a PI up to 15 (before treatment) is acceptable.
Passing 75 micron:	5% min, 15% max.
Soaked CBR at 93% Mod.AASHTO	20 minimum
The foamed bitumen properties should be:	
Expansion ratio, minimum	15 times
Half life, minimum	15 seconds

The foam bitumen treated material should comply with the following (Lewis, undated):

Table 2.5.2 Foam Stabilised Material Requirements.

Property	E0 to E2 traffic*	E3 and E4 traffic**
Marshall stability at 25°C	8 kN min	10 kN min
Retained stability at 25°C	60% min	70% min
Indirect tensile strength (dry)	100 kPa min	150 kPa min
Resilient modulus at 25°C	900 MPa min	1500 MPa min
Dynamic creep at 25°C	10 MPa min	15MPa min
Voids in mix	5% to 15%	

Note : * Very light to medium traffic roads with E80/lane < $3x10^6$

** High to very high traffic roads with E80/ lane < 3- $50x10^6$.

2.6 PERFORMANCE OF FOAM BITUMEN STABILISED MATERIAL IN DIFFERENT CONDITIONS

2.6.1 INITIAL TRIALS

In the earliest tests on the product by Csanyi (Csanyi,1957) in 1956 a trial section of approximately 2.5m wide x 6.1m long and with 150mm thick foam stabilised soil was laid using soil stabilised in a plant and transported to the test area. The important thing to note here was that it was possible to spread the plant mix by means of a rake. This has great relevance in labour-based construction. The material having been spread was then compacted by a pneumatic roller and monitored over a week. There was no settlement, ravelling or rutting in spite of the heavy rain that fell during the period. Slight scuffing of the surface occurred and this led to the decision to seal the surface with a single layer of a sand seal. Four months later the road was performing well and had withstood heavy rain, snow and ice on the surface and large temperature variations. Similar tests were carried out on in-place stabilised soil and these produced the same result.

2.6.2 EFFECT ON BASE COURSE

Studies in Kuwait (Bissada, 1987), which has very high ambient temperatures, investigated the use of foamed-bitumen stabilised local sand. This was of particular interest because there was a lack of or limited supply of good quality coarse aggregates and an abundance of poorly graded sands that are unsuitable for base layer construction. This is a situation similar to some parts of South Africa. Another reason for the interest was the high susceptibility of the asphalt pavement to deformation rather than to fatigue cracking in ambient temperatures of 15°C to 55°C.

To study the effect of different climatic conditions typical in hot climatic regions, Bissada (1987) used three different grades of bitumens: AC-20, AC-2.5 and a vacuum asphalt residue (VAR) and simulated the following curing conditions of the test samples:

a) In air at 23°C depicting dry conditions.
b) In a humidity chamber (at 23°C) with 100% humidity. This depicted humid low temperature conditions in this type of hot weather climate.
c) In an oven at 40°C depicting local dry conditions.

For the various grades of bitumen, the properties were measured in terms of their foam expansion ratios and half lives. The VAR grade was found to exhibit the lowest viscosity and the highest expansion ratio and half life values at all the foaming temperatures of 60, 135, 150 and 165°C and the moisture contents considered. The table below summarises the properties of the bitumen.

Table 2.6.2.1 Asphalt Properties

Property	Bitumen Grade		
	AC-20 (similar to 60/70 pen bitumen)	AC-2.5 (similar to 80/100 pen bitumen)	VAR(similar to cutback bitumen)
Penetration at 25°C(0.1mm)	67	135	310
Softening point(°C)	51	45	36
Viscosity(MPa/sec) at:			
60 °C	$2.8*10^5$	$3.5*10^4$	$5.0*10^3$
135°C	$5.2*10^2$	$2.4*10^2$	$1.5*10^2$
150°C	$3.0*10^2$	$1.4*10^2$	$0.9*10^2$
165°C	$1.2*10^2$	$0.8*10^2$	$0.5*10^2$
Specific Gravity	1.030	1.01	1.005

Foamed bitumen mixtures made with AC-20 which had an expansion ratio of 9 and half life of 8 seconds gave the lowest Marshall stability. Foamed bitumen AC-20 did not have good mixing properties with sands used in the study having stickiness and lumping problems. The AC-2.5 and VAR with high expansion ratios and half lives did not have the same problems.

By visual examination of the mixtures it was concluded that the VAR had the best aggregate coating in terms of uniformity. This suggests that the lower the viscosity the better the aggregate coating achieved.

It should be noted that in these experiments increasing the bitumen content did not improve the Marshall stability but caused the reverse effect. Curing AC-20 soil stabilised mixtures at 40°C over a three day period showed that the stability of the mixture increases with curing time for a particular bitumen content. A comparison of the effect of bitumen content on the stability of a hot asphalt mix and that of a foam mix showed that maximum stability of foamed-bitumen specimens was 1.5 to 2.0% less bitumen than for a hot mix specimen. Improving the grading of a sand to be stabilised improves the foamed-sand mix.

2.6.3 EFFECT OF CURING CONDITIONS

Analysing the results of the tests carried out by Amir Bissada (1987) the following deductions were made:

* Moisture loss from time of moulding the specimens is accompanied by an increase in stability.
* The highest rate of gain of the stability was obtained with the oven cured specimens at 40°C which achieved maximum stability in 3 days.
* Curing in the humidity chamber gave the slowest rate of gain of stability. 50% of stability was obtained after 14 days of curing.
* The air cured specimens achieved maximum stability equivalent to the oven cured specimens after 21 days.
* There was no direct relationship between loss of moisture and strength gain. This suggested that other factors such as aging of the binder may be playing a role.

It was concluded that at pavement service temperatures above 30°C foamed bitumen mixes give higher tensile strengths and resilient modulus than for the corresponding hot asphalts at elevated service temperatures.

Measured against the criteria of subgrade deformation, foamed bitumen base and subgrade layers are superior to unbound materials like sand - gravel mixes.

At local prevailing temperatures (Mean Annual Average Temperatures of 31°C) foamed bitumen mixes are equivalent to the corresponding hot sand asphalt mixes. Looking at cost effectiveness, foamed bitumen seems to be a better option than the conventional hot asphalt mixes or the granular base materials depending on the haulage distances. At high temperatures foamed bitumen base layers show superior resistance to permanent deformations than the corresponding hot asphalt layers. In these situations foaming should be adopted.

2.7 DESIGN CONSIDERATIONS FOR LABOUR INTENSIVE CONSTRUCTION

In addition to the factors given in the above text, the following should be noted in labour intensive construction:

- Binder proportion and type should be such as not to lead to excessive stickiness. The binder used should meet the requirements of a high expansion ratio and a high half life.
- The biggest advantage of foamed bitumen is its ability to be stockpiled for long periods after mixing but before compaction. This means that labour intensive construction can be accommodated in that a machine to foam the bitumen may be used and materi[illegible]piled for use by the labourers who will be laying the material at a s[illegible]e.
- Foamed asphalt would be id[illegible] areas where there are no suitable aggregates for road constr[illegible] or where the haulage distance to suitable material is uneconomical, as [illegible] local marginal material can be utilised.

It has been shown in laboratory tests done that the foam bitumen briquettes are generally weak in creep deformations. This was attributed to the low bitumen content of the foam bitumen. It is advised that some form of lateral support should be used in practice to restrain the foam bitumen eg. placing of kerbs along the road or raising the edges of the supporting material to same level as the foamed bitumen surface.

Methods needed to make labour-based application successful:

The high standards of construction must be maintained in labour intensive construction. Setting out of the road and the line and level control must be accurate. To maintain good compaction levels, it is suggested that a trial section should be done to assess loose layer thickness required to produce desired compacted thickness (in the tests done by Csanyi (1957) it was noted that placing the foamed bitumen base to an uncompacted depth of 6 inches or 150 mm gave a sufficient compaction at 5 inch thickness i.e. 125mm). The moisture content should be controlled and measurement of riding surface etc should be done to ensure compliance with the specifications.

Level of expertise:

As in the conventional construction methods, good organisation, planning and management are required for a quality product.

Level of Contractual skills:

Similar to earthworks jobs but tolerance measurement is more important and high density essential. It has been recommended that a compaction of 98% of Mod. AASHTO maximum density should be aimed for.

Productivities :

In a labour intensive project done on the Ethani Road in Embo, KwaZulu- Natal (Lewis, undated), it was possible for a work force of 25 local labourers to construct a road 1500m long and 4.5 metres wide within 17 weeks. The activities involved included the road bed preparation, application of a "foamed base", asphalt surfacing and asphalt berms. The foamed bitumen base was placed by hand using rakes and shovels. In this project it was found that 10 men could spread and compact $30m^3$ a day, an average productivity per man of three cubic metres a day.

Laying Techniques:

The laying technique used in labour based construction is different to that employed by machine intensive construction. In machine intensive work, the grader normally spreads a thin layer of material over the surface and then each thin layer is compacted by a roller. In labour intensive construction, the loose material to be compacted is normally spread in one operation. An initial rolling is then carried out, resulting in some hollows and bumps showing in the surface. More loose material is then added to the hollows and the bumps are cut to level. The material is then compacted again and the levels are re-checked. This operation of adding more material to the hollows and cutting the bumps is repeated until the levels are correct. Final shaping and compaction are then done.

The most important thing in the laying of foamed bitumen bases or sub bases is that the correct density should be achieved and the method used by Csanyi (1957) is a very useful one. In a trial section, Csanyi found that a loose layer thickness of 150mm gave him a compacted layer of 125mm at the specified densities thickness with the material that he used. It should be noted that in general layer thickness is not an accurate indicator of density.

3.0 REVIEW OF PREVIOUS WORK

3.1 NORWAY

3.1.1 Summary of Norwegian use of Foam Bitumen

The following information is based on the data presented by representatives of the Icopal Group, one of Norway's leading Contracting firms, at a seminar in South Africa. Icopal has representations in seven (7) European countries as well as in Canada and in the USA and therefore has extensive experience.

In the group, the countries that deal specifically with road construction are Denmark and Norway and these do more work in emulsions than in foamed bitumen. For purposes of this study, only work done in Norway is made use of.

Norway is a country with a population of four million people and has a length of 2700 km. The maximum load limit on most roads is 100kN axle (up to 14 000 ADT). Most roads, 60 - 80%, are classified as low volume roads.

Major coldmix research projects have been done using gravel emulsions (emulsion stabilised gravels) for surfacings (40mm) and road bases as well as foam bitumen for road bases. The distribution of work done is as follows:

Table 3.1.1 Use of Foam Stabilisation and emulsions in Norway

TECHNIQUE	FOAM	EMULSIONS
In-place Milling	1 300 000m^2	2 700 000m^2
Plant Mix	640 000m^2	700 000m^2

The traffic limits for the different techniques used at different depths are:

Table 3.1.2 Traffic limits for Foam in Norway

TECHNIQUE	Depth 0-100 (Upper Base)	Depth 100-200 (Lower)
Inplace Milling	1 500 AADT	3 000 AADT
Plant Mix	3 000 AADT	5 000 AADT

The use of foam (and emulsions) is picking up in Norway due to the fact that most roads are far from hot mix plants and economically it becomes more feasible to use the foam option. Graders and pavers are normally used to mix and lay the foam.

Problems peculiar to Norway are:

1. The aggregate is acidic and only cationic emulsion mixes are suitable. The cationic mixes break easily and cause lumps of bitumen to form disrupting the mixture quality.
2. The weather is very unstable and it can rain any time.

The aggregate used is normally found locally and is crushed where necessary by mobile crushing machines. This causes the further problem of dust coating which the French do away with by washing the aggregate. The Norwegians try not to wash the aggregate.

The grading of the aggregate used is based on the percentage passing the 75 um sieve, 20% being the upper limit. For foamed bitumen the percentage of fines is between 5 and 15% while for gravel emulsions (emulsion stabilised gravel) it's kept between 1 and 7%.

For the type of material used in Norway, the P.I. is not a problem as the material is not plastic. For very wet areas or wet aggregate, the use of foam is preferred to that of emulsions as it reduces the amount of water to be added.

The experience in Norway shows that there is rising use of foamed bitumen as it has met the technical requirements of the Norwegians and has coped well with their peculiar problems of wet and dusty aggregates. But the figures show that inplace milling is very common and little work has been done with regards to the use of labour with this material, a factor which may be due to the high labour costs in Norway.

3.2 FOAM BITUMEN EXPERIENCE IN AUSTRALIA

3.2.1 Background

In Australia there exists a good network of roads and the traffic volume increase necessitates that the existing roads be upgraded or strengthened. The use of foamed bitumen as a stabilising agent has found a niche as the method can be used cost effectively to rehabilitate failed and fatigued pavements or to improve the properties of marginal road materials. The cost saving comes as a result of the fact that the existing material can be reused as opposed to the bringing in of new material, which is often scarce.

Another plus in the use of the foam stabilisation method has been the minimal disruption of traffic during the rehabilitation process.

The foam bitumen process was introduced in Australia (Macarone et al, 1993) as early as 1960, a few years after Csanyi had discovered the process, by Mobil. Their variant of the process had been patented by Mobil. The rising cost of oil and bitumen in the 1970s led to decline in use of foam bitumen. With today's technology and advances in the mix designs, the foam stabilisation was reintroduced into Australia by Emoleum Ltd at a competitive level.

The reality in most developed countries is that recycling of materials has to be accepted as the solution to the problem of ever increasing traffic loads while the crushed rock material for base construction is becoming progressively more scarce. A common method of stabilising has been the use of cement stabilisers. This method has shown some weaknesses however, such as shrinkage cracking and a reduction in the pavement stiffness early in the pavement's life. The solution to this has traditionally been to increase the asphalt overlay thickness. The alternative offered by bitumen based stabilisation is claimed to have a reduced cost and quicker construction times.

There are two methods of bitumen based stabilisation currently in use in Australia. The one is emulsion mixed in place or in plant and the other the use of foamed bitumen.

The use of foamed bitumen in stabilising the base course materials requires less water compared to emulsions and the mix consequently does not have to dry up before the required strength is achieved (emulsions have to lose water before gaining maximum strength). The curing of foamed bitumen has also been found to be unaffected by the weather conditions (Bergeron, 1992). In contrast emulsions are more affected by the prevailing conditions. If the temperatures are high the emulsion breaks early and gains strength at a faster rate than if the temperatures are low or the conditions are wet.

3.2.2 AUSTRALIAN FOAMED BITUMEN STABILISATION.

Design of the Foamed Bitumen Mixes

A small laboratory plant, which is a scaled down version of the one that will be used on the site, is used to determine the foamed bitumen characteristics. It should be noted that it is possible to use any bitumen as the foam can be designed for the particular application. Studies done in Australia show that there is no significant difference between results obtained while using class 170 (80/100 pen) bitumen or class 320

(60/70 pen). The characteristics that have been adapted for use in Australia are an optimum expansion of 15 times and a half life of 60 seconds which are normally obtained with a water content of 2.6% and an additive of 0.7%. The bitumen temperature is normally kept between 170°C and 190°C as it affects the foam expansion and half life.

The same rational approach as in asphalt design has been adopted in Australia and is summarised below.

- Obtain a representative field sample of crushed base material.
- Determine the grading of the crushed material
- Determine the optimum moisture content (O.M.C) of the foamed mix
- Prepare foamed bitumen samples
- Cure the samples for three days at 60°C
- Measure the resilient modulus (dry and wet) and creep using Materials Testing Apparatus (MATTA)

It is useful to note the following:

- The O.M.C for a foamed bitumen mix is usually 1% to 2% less than that of the neat granular material
- The moisture content of the aggregate prior to foaming is critical as it aids the dispersion of the foam through the material. The recommendation is that the material on a site should be brought as close to the O.M.C as possible before mixing.
- The creep resistance of foam bitumen has been found to be very good in studies that have done in both Australia and the UK (Macarone et al, 1993).
- The permeability of foam bitumen is reduced by a factor between 10 and 100 times when granular materials are foamed with 4% bitumen.
- The recommended minimum fines from experiments done on 20mm crushed stone was 8%.

CONSTRUCTION

The Stabilisation Equipment

Typically the Australians use the following equipment in construction:

-Caterpillar RR250 (a specialised pulverising mixer) or similar fitted with a foam spray bar and associated additive system (Caterpillar Publication, 1994).
-Bitumen Tanker specially fitted for feeding hot bitumen to the insitu mixer.
-Water cart for distribution of water to the aggregate.
-A grader of the CAT12 class (Caterpillar Publication, 1994).
-Single drum vibratory steel roller; 11tonne static weight such as the Dynapac CA25
-Pneumatic tyred roller; 19t (fully ballasted)

The Construction Procedure:

1. Pulverisation of the existing pavement by means of the CATRR250. This particular machine can pulverise material up to 330mm depth including 150mm asphalt layer. For depths of asphalt greater than this or for concrete surfaces other means should be used.

2. Check of material for grading adjustments if necessary.

3. Application of water to bring material to O.M.C.

4. Stabilisation with foamed bitumen.

5. Shaping, trimming, and compaction of the pavement. Conventional equipment is used for this operation and three to four hours is required, a saving of two hours on the cement stabilising process. The compaction up to 300mm depth can be done by the 15t

tandem steel roller without a pneumatic tyre roller having to pre-roll.

6. Application of a primerseal for protection of the foam stabilised base layer before applying a wearing course.

7. As necessary application of asphalt wearing course or final chipseal or slurry seal.

QUALITY CONTROL

The mixing of the bitumen into the material is done through special nozzles and is very accurately controlled. Periodic visual inspection for uniformity as well as binder content checks are done. The main parameters that are checked are:

* Grading
* Binder Content and dispersion
* Compaction (Nucleodensiometer)
* Resilient modulus.

Production rates can be between 1400 and 2500m^2/day depending on the depth.

3.2.3 PROJECTS CARRIED OUT IN AUSTRALIA

Rehabilitation of Somerton Road - Shire of Bulla, Victoria

The section was a 2km section of road on the Somerton Road and was situated 20 km north of Melbourne. The traffic on this road was 20000 vehicles per day with 15% heavy vehicles. The road was showing signs of distress with extensive cracking, rutting, patching and general shape loss. The pavement consisted of a granular material of about 400mm depth with a bitumen seal and a small section of road that had a 50mm asphalt overlay. From the deflection results 30% of the road was deemed to be in need of strengthening to resist the rutting induced by the heavy traffic.

The alternatives that were put forward for the rehabilitation of the road were;

a) Place a thick asphalt overlay
b) Cement recycling and thick asphalt overlay
c) Cement recycling and thin asphalt overlay.

Only the first two options were found to offer a suitable alternative to meet the required 20-year design life as well as to sufficiently counter the cracking that would be induced by the cement treated layer. The thin overlay option (third solution) would have only been suitable as a short term solution. The minimum asphalt thickness required to prevent cracks initiated in the cemented layer from coming through to the surface would have been at least 175mm.

The foamed bitumen alternative was considered on the basis that it offered a 40% cost saving as compared to both reconstruction and thick asphalt overlay. Refer to the table below for the predicted pavement lives of the conventional deep strength asphalt and foamed bitumen stabilisation alternative.

Foamed bitumen was adopted as it offered a longer predicted life at a reduced cost (40% less cost).

Table 3.2.3.1 Comparison of Rehabilitation Alternatives in Norway

COMPARISON OF TWO REHABILITATION ALTERNATIVES	
Deep Strength Asphalt	Foamed Bitumen Alternative
45mm wearing course 90mm intermediate asphalt layer 100mm base asphalt layer 150mm cement treated base	45mm wearing course asphalt 300mm Foamed bitumen layer
Predicted life: $3x10^7$ E80's	Predicted life: $5x10^7$ E80's

Work Program

To accommodate the traffic, the road was done in alternate sections 400m long. This allowed the completed section of road to be opened to traffic at the end of the day's work. It was found that the primerseal application and asphalt wearing course could be postponed for as long as two weeks in dry weather. In cases where rain was imminent, it was recommended that a primerseal be placed at the end of the day's work.

Field Performance

Compaction results as well as deflection and resilient modulus were done. The compaction required was set at a minimum of [illegible] d AASHTO. The results obtained were all above the requirement to the full dep[illegible] ([illegible]00mm) of the stabilised material. The wet modulus requirements were set at 1300MPa and again the foamed material was able to meet this requirement.

Another matter of note was that the deflection of this section of road was reduced from 0.7mm before stabilisation to 0.4mm after stabilisation. A further reduction in the deflection was envisaged as the foamed material gained strength.

STUD ROAD, ROWVILLE

This road is a highly trafficked arterial road in the eastern suburbs of Melbourne. The section of road had many edge defects and lacked stiffness as indicated by the curvature results. A number of sections had insufficient pavement depth. Due to the inadequate depth it was decided that the road would be rehabilitated for the short term period only. Again the foamed bitumen stabilisation was employed. Varying depths of foamed bitumen stabilisation was done from 150mm to 300mm. The 150mm section was also treated with 2% lime. A 35mm aspha[illegible] [illegible]yer was then applied to the whole section.

The results of curvature tests (similar to deflection tests) done two months later, showed that maximum curvature was reduced from 0.5mm to 0.3mm. This result does indicate a small gain in strength but there was a marked improvement in the uniformity of the results. Results of tests done seven months later were more varied and this was attributed to the drainage and subgrade conditions.

TULLAMARINE FREEWAY, MELBOURNE, VICTORIA

This road involved the upgrading of an emergency lane on the road linking Melbourne to the airport so as to accommodate the increasing traffic. The project involved the removal of two asphalt layers and then foam stabilising the 300mm layer of granular base material.

The new asphalt consisted of two layers of 50mm AC20 asphalt and 30mm of a polymer modified open graded asphalt as the wearing course. The work was done over the weekend to minimise traffic disruption. The foam stabilisation was done on the first day and then asphalt surfacing was done on the next day. A year later the road was still performing satisfactorily.

SPRING ROAD, CITY OF MOORABBIN, VICTORIA

The pavement exhibited signs of distress including potholing and cracking. The pavement consisted of 20mm of spray seal and 175mm of macadam over a heavy clay subgrade. Foamed bitumen stabilisation was chosen over cement stabilisation in this case because the pavement was very thin. Reconstruction would have been too expensive.

The rehabilitation was achieved by pulverising the pavement to a depth of 180mm and then foam stabilising the top 150mm and surfacing the road with 30mm AC10 asphalt overlay. Tests on cores taken four months after construction gave modulus values close to the design value of 2300MPa. The same road was found to performing

-ntly after seven months.

BROWNS ROAD, SHIRE OF FLINDERS, VICTORIA

Browns Road is a link road to the Mornington Freeway in the south eastern suburbs of Melbourne. The road had similar conditions to Spring Road. The foamed bitumen stabilisation was chosen in preference to reconstruction and cement stabilisation due to the lower costs and the elimination of shrinkage cracking.

The existing road consisted of sprayed seals over a low quality natural gravel. Rehabilitation consisted of adding a 100mm layer of 20mm crushed rock over the existing pavement and then pulverising and foam stabilising to a depth of 200mm. A double coat emulsion seal (size 10mm and 7mm) completed the surfacing. After nine months of service the road is performing well and there are no signs of shrinkage cracking.

3.2.4 SUMMARY

The Australian experience showed that:

1) Foamed bitumen pavements cure rapidly allowing early trafficking of the road and therefore minimal disruption to the road users in cases where a section of road is being rehabilitated.

2) The foamed bitumen material allows more time for compaction, shaping and trimming than cementitious pavements and the riding quality is not compromised.

3) The process of foaming the material is accurately controlled allowing specified quantities to be used.

4) Foamed bitumen is a cost effective and rapid method of road rehabilitation.

3.3 SOUTH AFRICA

3.3.1 Introduction

Several projects have been carried out in Southern Africa and valuable information has been obtained with regards to the characteristics and properties of the product as well as the practical implications of foamed bitumen.

Some early work was done on the feasibility of stabilising sands by using foamed bitumen (Marais, 1977). The work suggested solutions for the particular problems that were being experienced in South West Africa (Namibia) because of the Kalahari sand and calcrete that are readily available. The use of foam bitumen was one of the solutions that were proposed. Subsequently some experimental sections were done in Okatana, Namibia (Joubert et al, 1989). The results of the experiments, done over a period of four years, concluded that foam bitumen stabilisation was a feasible solution provided that sound engineering and construction practices were used.

Some of the more recent projects that have been done include the following:

- Mbazwana to Sodwana Bay - a road rehabilitation project (Lewis, undated)
- Cliffdale Road Trials -a road rehabilitation project (Lewis, undated)
- Embo Valley Trust – a labour intensive project (Hefer, 1995)
- Soweto project with the use of stabilised gravel (Jenkins, 1994).
- Various Projects involving insitu recycling of materials (Hefer, 1995 and Lewis, undated).

The scenario in South Africa is often that of upgrading roads from dust roads to black top roads and the provision of infrastructure such as roads. There is a lot of potential for the employment of the people who need these services when the projects are being carried out. If this potential is utilised to its fullest extent there would be positive effects such as more money going into the community. A lot of emphasis has been placed on the rehabilitation of roads. This study is based on materials obtained from a road project in Duku Duku which aimed at providing access to the rural folk living in this sandy area on the North Coast of Natal.

The use of foam bitumen is of particular interest in areas that have marginal road building materials such as sand. Areas where the utilisation of hard aggregates is very expensive, due to long haulage or due to the need for crushing the aggregate, should consider foam stabilisation.

3.3.2 A Review of Projects Carried out in South Africa

Mbazwana to Sodwana Bay

This project was done in 1994 and the length of road that was done was 11.2 km of the Provincial Road P466. The situation here was that the local material was a marginal road building material consisting of a single sized sand with 100% passing the 2mm sieve and 2% passing the 75-micron sieve. The closest source of good road building material (gravel) was at least sixty (60) km away.

It was more cost effective to treat the existing local material than to transport the gravel to the site. The foam stabilised sand was used as a 150mm base course layer. The mix design recommended the addition of 2% cement to improve on the low filler percentage. The original mix design was done by the equipment suppliers (in Canada) and then redone in R.S.A. See Table 3.3.2.1.

Table 3.3.2.1 Early Tests on Foam in Mbazwana to Sodwana Bay Project

Parameter	Original Mix Design Canada	Mix Design (RSA)	Typical Field Results	Cores after 1 Yr
Bulk Relative Density	1.784	-	-	1.835
Max Theo. RD	2.474	-	-	2.444
Void Content	27.8	-	-	24.9
Soaked Stability(kN)	7.3	6.7	5.1	-
Dry Stability (kN.)	9.7	9.0	5.6	-
Retained Stability(%)	75.6	74.4	91.1	
Resilient Modulus	-	-	1212	2026
Dynamic Creep	-	-	16.6	31.0

In this project a few practical lessons were learnt. The first was that because the underlying subgrade was of cohesionless sand it was very difficult to work over it and the problem was compounded by the fact that the underlying material tended to dilute the foam base course layer. These problems were surmounted by the use of two layers to make up the 150mm base course.

The first layer then provided a platform for the second layer. The project also discovered it did not seem to make a difference whether the foam layer was protected by a slurry seal layer or not as the sections that were sealed performed as well as the unsurfaced sections. The development of the strength of the foam treated pavement with time was found to be excellent with the DCP probe failing to penetrate the layer. The results of tests done on cores taken are given in Table 3.4.2.1. The road is performing well with no rutting in spite of the heavy traffic from logging trucks and adverse weather conditions.

Cliffdale Road Trials

As a result of the success of the Mbazwana to Sodwana Bay project the Department of Transport decided to do another section on the heavily trafficked Cliffdale road (Road P504). The traffic count here was 350 vehicles per day. The section of road had steep gradients of about 15% and also had curves. The material was foamed in March 1995 and then stockpiled until July 1995 when the material was placed using a motor grader. During the stockpile period the material was uncovered. The results of tests after two weeks and after two months are given in the tables below. The results give an insight into the possibilities of foam bitumen.

1) Weathered granite treated with 3.5% foamed bitumen and 1% road lime

Table 3.3.2.2 Cliffdale Road Trials: Weathered Granite

Parameter	Plant Mix After 2 Weeks	Plant Mix After 2 Months
Dry Stability(kN.)	13.7	12.5
Soaked Stability (kN.)	11.5	7.3
Retained Stability	83.9	58.4
Resilient Modulus	-	-
Dynamic Creep(MPa)	-	83.3

2) 80% RAP + 20% crusher dust treated with 1.7% foamed bitumen

Table 3.3.2.3 Cliffdale Road Trials: RAP

Parameter	Plant Mix After 2 Weeks	Plant Mix After 2 Months
Dry Stability (kN.)	23.7	23.7
Soaked Stability(kN.)	17.4	19.1
Retained Stability	73.4	80.6
Resilient Modulus(MPa)	1503	1453
Dynamic Creep (MPa)	-	14.5

Embo Valley Trust- Labour Intensive Project

This project was the first project in South Africa (1994), if not in the world, to employ labour intensive methods of construction with foamed bitumen. Foam stabilisation was found to be more viable on a cost basis than the suggested alternative of a concrete pavement. The foam pavement also had the distinct advantage that the road would be kept open during construction. In this project two teams were used, one to lay the foam bitumen and the other to do the surfacing. In the steeply graded areas the foam was placed in layers of 150mm and in the better areas the layer thickness used was 125mm. The surfacing was a hot mix asphalt surfacing of 25mm. The rate at which the work was carried out averaged 3 m^3 per man per day, spreading and compacting. The compaction was done by a Bomag 90 pedestrian controlled roller which was able to achieve the 98% MOD. AASHTO density specified. The compaction results were as shown in the table below:

Table 3.3.2.4 Cliffdale Road Trials: Compaction Results

Test Parameter	Value
MOD. AASHTO Density(kg/m^3)	2053
Bulk Relative Density	2.135
Average Field Density(kg/m^3)	1935
Percentage Compaction based on: a) Moisture/ Density b) Bulk Rel. Density	 96.7 93.0

The road is serving the community well, showing no signs of distress in wet conditions. The community can also pride itself for having built the road. This project showed that the ability of foam stabilised material to be stockpiled for a long time can be utilised in labour-based construction.

3.3.3 SUMMARY

South Africa has the technical capability of making use of the various methods of utilising foamed bitumen including modifying current standard equipment for use in foam bitumen manufacturing (Hefer, 1995). Some other advantages that can be utilised by using foamed bitumen are quicker construction times (Akeroyd, 1989), durability to combine the advantages of using both cold and hot mixes (Custedo et al, 1983) and economic viability as it can cut costs by up to 60% (Soter, 1994 and Akeroyd, 1989).

The unique element of the South African experience with foamed bitumen has been that an attempt at integrating the machinery used in the process of producing the foamed bitumen and labour intensive methods of construction has been successful. This was mainly due to the fact that the foamed material could be stockpiled for a long time. More knowledge has been gained on the properties, mixing techniques and compaction of foam bitumen. It has been found to be a practical and a less expensive alternative for areas where good quality road building material is difficult to find.

4.0 EXPERIMENTAL DESIGN

4.1 Stockpile Life of Foamed Bitumen

It has been suggested that foamed bitumen can be kept up to three months in a stockpile and still be used successfully in the field without much effect on the properties of the foamed bitumen (Lewis, undated). This experiment is aimed at quantifying this in terms of the strength loss of the foamed bitumen. It is the goal of this experiment to determine the limit for the stockpile life of foamed bitumen with some degree of precision.

The aim here is to investigate the following aspects:

- To test the theory that a protective membrane or crust forms around the stockpiled material retaining moisture within and/or retaining the properties of the material. To achieve this, the material at the surface, to a depth of 100mm, was tested and the results compared to the results obtained by testing the materials from deeper within the stockpile.

- To find if stockpiling results in an increase in the hardness of the material which ultimately affects the workability and compactibility of the material when required for use in the field.

- To test whether the strength is influenced by wetting and drying cycles during the stockpile life. To achieve this objective part of the material was exposed to the weather elements and another part of the same material was protected from the weather elements by covering it up.

4.2 Tested Parameters

a) Protective Coat -: The Marshall stability tests were done at different positions on the surface and inside the stockpile. The aim was to determine whether there was any variation between the strengths observed on the surface layer (depth of 100mm) and the strength in the middle of the stockpile. Testing the surface layer consisted of sampling the material to a depth of 100mm at the various positions as shown in the Figure 4.5.1. A garden trowel was used in the first instance to assess the workability of the different materials. If the material was not sufficiently workable, the shovel and the pick were then considered.

b) Effect on Compaction Effort required - concern here was that the same compactive effort would yield a decreasing density with time due to the consolidation of the stockpile. To determine the validity of this assertion, standard density tests of materials from the same relative positions were done over time.

c) Strength - The design parameters that are used currently in South Africa, refer to the South African experience in chapter 3.4, require that either the dry and wet Marshall stabilities or the dry and wet Indirect Tensile Strength (ITS) be done and subsequently the retained strength is determined. The required values for acceptability of a foam mix have been given in the second chapter. These parameters were used to determine whether the stockpiled material was deteriorating to a point that was unacceptable by measuring the values at varying time intervals.

The test method that was chosen and that has been adopted by Bitutek Laboratory (a leading laboratory in the testing and designing of the foamed bitumen in South Africa) has been the ITS method due to the fact that the readings are quite substantial in the order of hundreds and this makes it easier to determine small variations as compared to the Marshall test which gives small figures of the tenth order and consequently require very accurate machines to measure small variations.

d) Other tests done on the material were (TMH1, 1986):

i. The Moisture Density relationship

ii. Moisture content determination

iii. Binder content determination

iv. Bulk relative densities

v Microscopic analysis of the material.

4.3 Materials to be Tested

a) Foamed sand from the Duka-Duka project. (Refer to Appendix A for material characteristics)

b) Recycled Asphalt (RAP) from Colas

c) Foamed gravel from a Soweto project.

4.4 Standardisation of Moisture Contents Before Laboratory Tesiting.

Any tests that were to be done on the material were to be tested under standard conditions so that comparisons could be drawn between the different results obtained. The moisture content was one of the conditions that was crucial to ensuring that the material was under the same conditions.

To determine the effect of the moisture content on the properties of the foam stabilised material an initial control experiment was done on the material as it was found on site and another was done on the same material after adjusting the moisture content to the optimum moisture content.

The foam stabilised gravel results at 12 months in Stockpile:

Table 4.4.1 Foam Stabilised Gravel: Effect of Moisture

Position	B6	4	6	7	B6	4	5	7
Moisture Content	14.9	6.1	11.2	11.6	15.1	10.7	10.7	10.7
Binder Content	2.9	2.9	3.2	2.4	2.9	2.9	3.2	2.4
B.R.D	1.933	1.86	2.028	2.039	1.966	2.033	2.045	2.046
Dry ITS	258	159	415	427	237	339	364	39[illegible]
Wet ITS	*	*	*	*	[illegible]	*	*	*
Retained	-	-	-	-	-	[illegible]	-	-

Note: * Means sample collapsed

B6 represents material that was sampled and bagged after 6 months and kept for another 6 months.

Unshaded area represents material as found on site.

Shaded area represents material adjusted to O.M.C.

Foam Stabilised RAP: At Month 2 in stockpile:

Table 4.4.2 Foam Stabilised RAP: Effect of Moisture

Position	RT	1	4	5	7	RT	1	4	5	7
M/C	3.9	2.9	3.5	4.9	3.4	6.0	6.0	6.0	6.0	6.0
Binder Content	5.8	6.6	6.5	7.1	7.8	5.8	6.6	6.5	7.1	7.8
B.R.D	2.159	2.04	2.058	2.05	2.06	2.052	2.061	2.066	2.051	2.107
Dry ITS	707	479	587	566	470	494	471	562	573	561
Wet ITS	541	385	384	465	408	395	420	441	505	409
Retained	76.5	80.4	64.2	[illegible]	86.8	80.0	89.2	78.5	88	72.9

Note: Unshaded area represents material as found on site.

Shaded area represents material adjusted to O.M.C.

R.T refers to foam RAP treated with 1% OF 30% emulsion.

Foamed Sand Material: At Month 0:

Table 4.4.3 Foam Stabilised Sand: The Design

Position	M/Content	B/Content	Bulk R.D	Dry ITS	Wet ITS	Retained ITS
1	13.7	5.0	1.765	267	189	70.8
1	10.3	5.0	1.767	250	186	74.4

Note : Shaded area represents material adjusted to O.M.C.

OMC = 10.3%

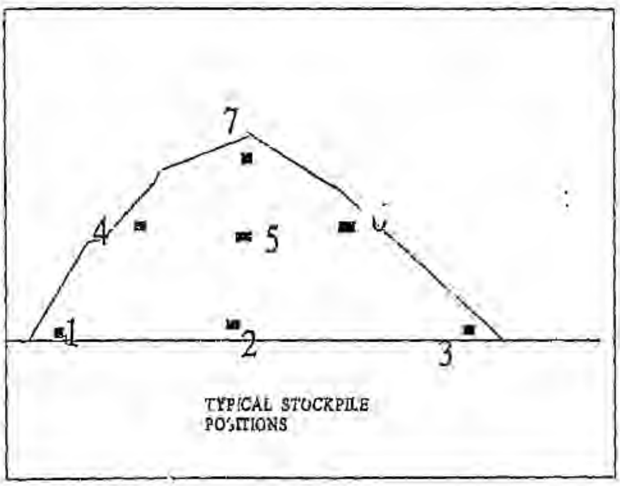
The above results show that the foamed material parameters were altered by the adjustment of the moisture content to O.M.C. Because of the effect of moisture, and the fact that the material would be brought to OMC at the time of construction, all subsequent samples tested were brought to O.M.C before laboratory testing was done.

4.5 Stockpile Layout

The materials tested were placed in a conical shape in the stockpile resting at their natural angle of repose. The positions 1, 4, 7, 6 and 3 were 100mm from the surface of the material. Positions 5 and 2 were from inside the stockpile. It should be noted that positions 1 and 4 are symmetrical to positions 3 and 6. For this reason and for purposes of saving on the material required for the study one stockpile was used for the covered and uncovered stockpile investigation. One side of the stockpile was covered and the positions named as for a separate stockpile ie position 3 and 6 were called 1 and 4 respectively.

Figure 4.5.1 below shows the arrangement of the tested positions.

Figure 4.5.1



TYPICAL STOCKPILE POSITIONS

5.0 TESTING PROGRAMME AND RESULTS

5.1 Material: Foam Stabilised Sand (ex Duku Duku)

5.1.1 Original Design:

General

The design of foam bitumen is done in the laboratory by use of a small plant which is designed to mix small quantities of foam for the purpose of making test samples. The specimens made are normally tested by means of Marshall tests. Marshall briquettes are made and are then cured by leaving the briquettes in their moulds for twenty four hours at ambient temperatures and then the samples are extracted and further cured at 60^{0}C for twenty four hours. The specimens are ready to be tested on cooling.

The choice of the optimum binder content of a mix is determined on volumetric and Marshall curves as for the hot mixed asphalt. The exception is that the briquettes here are not soaked at an elevated temperature prior to the Marshall tests or I.T.S test. Instead the susceptibility to moisture of the material is checked by doing additional Marshall tests or I.T.S test on samples previously soaked at reduced pressure. A minimum retained stability of 60% is required. The resilient modulus test and the dynamic creep are carried out to assist in the determination of the optimum binder content.

Aggregate

The aggregate contained a mixture of two materials as follows:

a) Dune Sand 60%

b) Berea red sand 40%

To the mixture 1% cement was added

The material grading of the mix is shown in Appendix A

<u>Foamed Bitumen Mix</u>

The above aggregate was mixed with 150/200 pen bitumen from SAPREF and the various mixtures tried are shown in Appendix A.

Below is the final mix design adopted for the foamed sand mixture.

Table 5.1.1 Foam Stabilised Sand: The Design.

Mix NO_	binder content	m/c	B.R.D	ITS (wet)	ITS (dry)	ITS retained	Dynamic creep(MPa)	Resilient Modulus
1	3.5%	8.3%	1.980	256	415	61.7%	68	3616
2	3.5%	8.8%	1.985	196	329	59.5	100.5	3743

Note: Aggregate for both mixes contained 75% of dune sand and 25% berea red.
Mix number 2 contained 1% cement and mix number 1 had no cement.
Mod AASHTO of the mix was 1868k_/m3
Optimum moisture content (O.M.C) was 9.3%
Fill area represents the adopted design

5.1.2 Stockpile Experiment:

Duku Duku sand was foamed in May 1997 in order to provide a black top road to this rural community. Six tonnes of the material were then transported to Durban where it was placed in a stockpile. As the material was too little to provide two separate stockpiles, one stockpile was made into a conical shape and one half of the stockpile was covered with canvas.

The following tests were then carried out on the stockpile:

- Strength with time (performance over a four month period) - Investigated by means of the Indirect Tensile Strength (ITS) on the soaked and dry samples. Refer to section 5.1.3 for the results.

- Workability with time - Manual labour was engaged about once a month to work the material during the sampling with aim of determining the point at which the material became unworkable. The worker was given a garden trowel and was asked to sample the material at the various positions as determined by the testing program. His assessment of the ease with which he was able to collect the samples was recorded (refer to table 5.1.2). The foamed sand proved to have minimal problems and though tests were done over time there was no change in the workability of the material. A garden trowel was sufficient to work the material.

Table 5.1.2 Foam Stabilised Sand: Workability

Material: Foamed Sand Mixture		
Position	**Penetration by garden trowel**	**Worker's Classification**
Top 0.5m deep	Easy	very workable
Middle 0.5m inside	Easy	very workable
Surface (100mm depth)	Easy	very workable

Note : Tool used by worker was in all cases a garden trowel.
Measurements were the same for the duration of the project.

- Compactibility of the material with time. It is to be determined whether the same effort will yield a progressively diminishing density as the material ages. To achieve this, the material was compacted according to Marshall procedure for making samples and the bulk relative densities were recorded. Refer to Figures 5.1.4 and 5.1.5

- The moisture contents at all positions sampled (refer to Fig 4.5.1) within the stockpile were taken, without adjustment of moisture content, and examined to determine if there is a relationship between the relative position in the stockpile and the moisture content. It is hoped that some light will be shed on the existence or lack of a protective coat around the material in the stockpile.

5.1.3 Results

a) Moisture Density Relationship

The moisture contents at which the Marshall properties are carried out will greatly influence the results obtained. To obtain a common base for comparison purposes the optimum moisture content had to be determined and then served as the common denominator for all subsequent tests. The maximum dry density was also useful in determining the percentage compaction achieved using the Marshall method. Refer to Appendices A for a graphical illustration of the moisture-density relationship.

Test results at Start: Month 0

Table 5.1.3.1 Foam Stabilised Sand: Result Month 0

Position	1
Moisture content	13.7%
Binder Content	5%
B.R.D	1.787
Dry ITS	250
Wet ITS	189
Retained	74.4%

Note: Fill area represents the covered area of stockpile
All results were obtained at O.M.C

Test Results: Month 2

These results were the average of random samples taken from the mixture after transportation to Durban and represent the average of the whole stockpile just before one half of the stockpile was covered. All positions will therefore have the same values for each measured parameter.

Table 5.1.3.2 Foam Stabilised Sand: Result Month 2

Position	1
M/C	9.4
B/C	5
B.R.D	
Dry ITS	214.5
Wet ITS	207
Retained	96.5

Note: Fill area represents the covered area of stockpile
All results were obtained at O.M.C

Test Results: Month 3

Table 5.1.3.3 Foam Stabilised Sand: Result Month 3

Position	1	4	5	7	1	4	5	7
m/c	10.1	10.7	-	-	9.2	7.8	8.8	8.2
B/C	4.5	4.4	-	-	4.5	4.4	4.1	4.4
B.R.D	1.84	1.868	-	-	1.854	1.842	1.862	1.841
Dry ITS	257	275	-	-	247	221	214	240
Wet ITS	185	189	-	-	208	178	160	172
Retained	72	68.7	-	-	84.2	80.5	74.8	71.8

Note: Fill area represents the covered area of stockpile

All results were obtained at O.M.C

Test Results: Month 4

Table 5.1.3.4 Foam Stabilised Sand: Result Month 4.

Position	1	4	5	7	1	4	5	7
m/c	9.1	8.1	8.2	6.7	8.7	7.3	10	7.1
B/C	4.8	4.2	4.9	4.9	4.6	4.7	4.2	3.7
B.R.D	1.862	1.855	1.848	1.843	1.849	1.839	1.856	1.656
Dry ITS	228	193	182	180	206	240	237	179
Wet ITS	135	120	126	113	133	189	176	132
Retained	59.2	62.2	69.2	62.8	64.6	78.8	74.3	73.7

Note: Fill area represents the covered area of stockpile

All results were obtained at O.M.C

5.1.4 Statistical Analysis

Table 5.1.4.1a Bulk Relative Density: Uncovered

Time (Months)	Position 1	Position 4	Position 7	Position 5
0	1.787	1.787	1.787	1.787
3	1.84	1.868		
4	1.862	1.855	1.843	1.848

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	5.361	1.787	0
Row 2	2	3.708	1.854	0.000392
Row 3	3	5.56	1.853333	9.23E-05
Column 1	3	5.489	1.829667	0.001486
Column 2	3	5.51	1.836667	0.001892
Column 3	2	3.63	1.815	0.001568

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.689102	2	0.344551	0.909481	0.47253	6.944276
Columns	0.776747	2	0.388373	1.025156	0.437084	6.944276
Error	1.515374	4	0.378843			
Total	2.981222	8				

Table 5.1.4.1b Bulk Relative Density: Covered

Time (Months)	Position 1	Position 4	Position 7	Position 5
0	1.787	1.787	1.787	1.787
3	1.854	1.842	1.841	1.862
4	1.849	1.839	1.856	1.856

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	5.361	1.787	0
Row 2	3	5.537	1.845667	5.23E-05
Row 3	3	5.544	1.848	7.3E-05
Column 1	3	5.49	1.83	0.001393
Column 2	3	5.468	1.822667	0.000956
Column 3	3	5.484	1.828	0.001317

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.007168	2	0.003584	87.18106	0.000503	6.944276
Columns	8.62E-05	2	4.31E-05	1.048649	0.430373	6.944276
Error	0.000164	4	4.11E-05			
Total	0.007419	8				

Table 5.1.4.1a shows that the F-values for both the rows and the columns are below the critical F-values of 6.944276. This means that there is no significant variation in the bulk relative density at the 5% significance level.

Table 5.1.4.1b shows that the F-value of 1.04 for the columns is below the critical F-values of 6.944276. This means that there is no significant variation in the Bulk relative density for the covered stockpile with time at the 5% significance level. The rows however show that there is a significant difference in the bulk relative density by position in the covered stockpile since F= 87 is greater than F-critical.

5.1.4 Statistical Analysis

Table 5.1.4.2a Dry Indirect Tensile Strength: Uncovered

Time(Months)	Position 1	Position 4	Position 7	Position 5
0	250	250	250	250
2	214.5	214.5	214.5	214.5
3	257	275		
4	228	193	180	182

Anova: Two-Factor Without Replication

SUMMARY	Count	Sum	Average	Variance
Row 1	3	750	250	0
Row 2	3	643.5	214.5	0
Row 3	2	532	266	162
Row 4	3	601	200.3333	616.3333
Column 1	4	949.5	237.375	385.2292
Column 2	4	932.5	233.125	1331.729
Column 3	3	644.5	214.8333	1225.083

ANOVA

ource of Variation	SS	df	MS	F	P-value	F crit
Rows	8338.896	3	2779.632	0.482302	0.700536	4.757055
Columns	14688.17	2	7344.083	1.300714	0.339424	5.143249
Error	33877.17	6	5646.194			
Total	56904.23	11				

Table 5.1.4.2b Dry Indirect Tensile Strength: Covered

Time(Months)	Position 1	Position 4	Position 7	Position 5
0	250	250	250	250
2	214.5	214.5	214.5	214.5
3	247	221	240	214
4	206	240	179	237

Anova: Two-Factor Without Replication

SUMMARY	Count	Sum	Average	Variance
Row 1	3	750	250	0
Row 2	3	643.5	214.5	0
Row 3	3	708	236	181
Row 4	3	625	208.3333	934.3333
Column 1	4	917.5	229.375	501.2292
Column 2	4	925.5	231.375	271.2292
Column 3	4	883.5	220.875	1002.729

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	3343.562	3	1114.521	3.373928	0.095624	4.757055
Columns	248.6667	2	124.3333	0.376387	0.701466	5.143249
Error	1982	6	330.3333			
Total	5574.229	11				

Table 5.1.4.2a) and b) shows that the F-values for both the rows and the columns are below the critical F-values of 4.757055 and 5.143249 respectively. This means that there is no significant variation in the Dry ITS for the uncovered and covered stockpiles both in terms of the position of the test and in time, at the 0.05 significance level.

Table 5.1.4.3a Wet ITS :Uncovered

Time(Months)	Position 1	Position 4	Position 7	Position 5
0	189	189	189	189
2	207	207	207	207
3	185	189		
4	135	120	113	126

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	567	189	0
Row 2	3	621	207	0
Row 3	2	374	187	8
Row 4	3	368	122,6667	126,3333
Column 1	4	716	179	952
Column 2	4	705	176,25	1470,25
Column 3	3	509	169,6667	2489,333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	17068,33	3	5689,444	2,033013	0,210834	4,757055
Columns	6782,167	2	3391,083	1,211738	0,361393	5,143249
Error	16791,17	6	2798,528			
Total	40641,67	11				

Table 5.1.4.3b Wet ITS ; Covered

Time(Months)	Position 1	Position 4	Position 7	Position 5
0	189	189	189	189
2	207	207	207	207
3	208	178	172	160
4	133	189	132	176

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	567	189	0
Row 2	3	621	207	0
Row 3	3	558	186	372
Row 4	3	454	151,3333	1064,333
Column 1	4	737	184,25	1243,583
Column 2	4	763	190,75	144,25
Column 3	4	700	175	1026

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	4870	3	1623.333	4.107105	0.066674	4.757055
Columns	501.1667	2	250.5833	0.633987	0.562618	5.143249
Error	2371.5	6	395.25			
Total	7742.667	11				

Table 5.1.4.3.a) and b) shows that the F-values for both the rows and the columns are below the critical F-values of 4.757055 and 5.143249 respectively. This means that there is no significant variation in the Soaked ITS for the uncovered and covered stockpiles both in terms of the position of the test and in time, at the 0.05 significance level.

Table 5.1.4.4a Retained ITS : Uncovered

Time(Months)	Position 1	Position 4	Position 7	Position 5
0	74.4	74.4	74.4	74.4
2	96.5	96.5	96.5	96.5
3	72	68.7		
4	59.2	62.2	62.8	69.2

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	223.2	74.4	0
Row 2	3	289.5	96.5	0
Row 3	2	140.7	70.35	5.445
Row 4	3	184.2	61.4	3.72
Column 1	4	302.1	75.525	240.0492
Column 2	4	301.8	75.45	221.7767
Column 3	3	233.7	77.9	293.11

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	3987.06	3	1329.02	3.144437	0.108039	4.757055
Columns	776.355	2	388.1775	0.918421	0.449777	5.143249
Error	2535.945	6	422.6575			
Total	7299.36	11				

Table 5.1.4.4b Retained ITS ; Covered

Time(Months)	Position 1	Position 4	Position 7	Position 5
0	74.4	74.7	74.4	74.4
2	96.5	96.5	96.5	96.5
3	84.2	80.5	71.8	74.8
4	64.6	78.8	73.7	74.3

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	223.5	74.5	0.03
Row 2	3	289.5	96.5	0
Row 3	3	236.5	78.83333	40.52333
Row 4	3	217.1	72.36667	51.74333
Column 1	4	319.7	79.925	186.1292
Column 2	4	330.5	82.625	91.48917
Column 3	4	316.4	79.1	135.7667

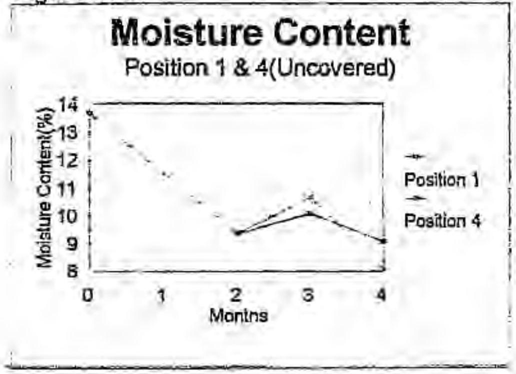
ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	1082.757	3	360.9189	13.75817	0.004254	4.757055
Columns	27.195	2	13.5975	0.518335	0.619944	5.143249
Error	157.3983	6	26.23306			
Total	1267.35	11				

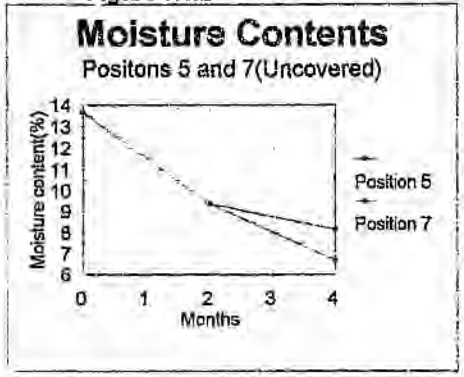
Table 5.1.4.4.a shows that the F-values for the rows and the columns are below the critical F-values of 4.757055 and 5.143249 respectively. This means that there is no significant variation in the Retained ITS for the uncovered stockpiles both in terms of the position of the test and in time, at the 0.05 significance level.

Table 5.1.4.4.b shows that the F-value of 13.758 for the rows is greater than the critical F-value of 4.757055. This means that there is a significant variation in the retained ITS for the covered stockpile with position at the 0.05 significance level. The columns however show that there is no significant difference in the retained ITS in time in the covered stockpile since F= 0.518 is less than F-critical.

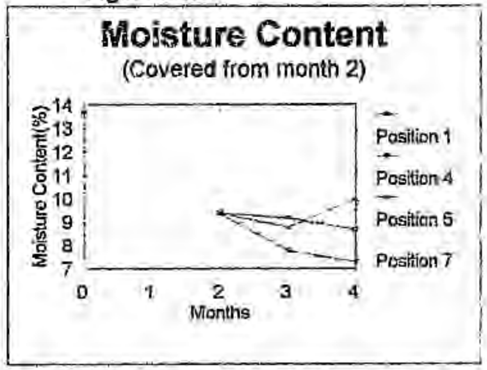
Material : Foam Stabilised Sand
Figure 5.1.1



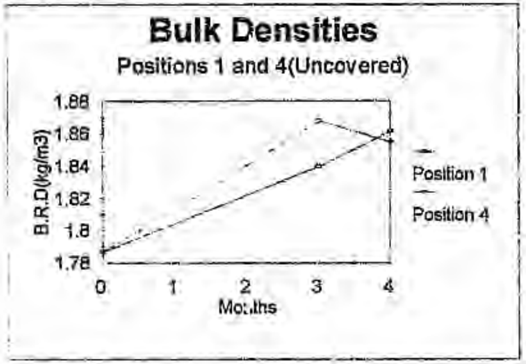
Material : Foam Stabilised Sand
Figure 5.1.2



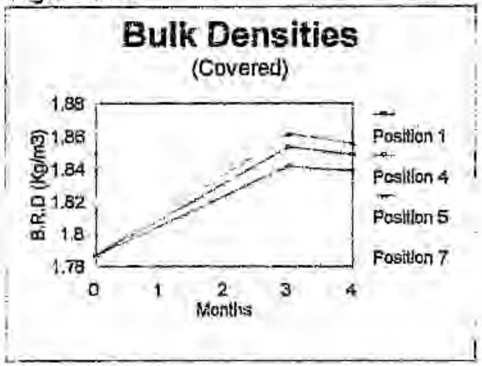
Material : Foam Stabilised Sand
Figure 5.1.3



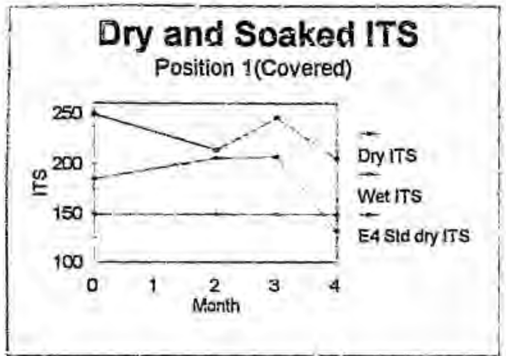
Material : Foam Stabilised Sand
Figure 5.1.4



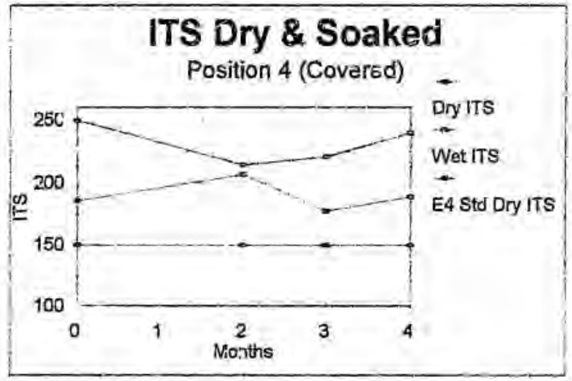
Material : Foam Stabilised Sand
Figure 5.1.5



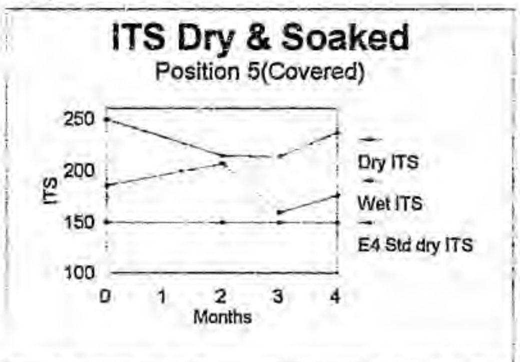
Material : Foam Stabilised Sand
Figure 5.1.6



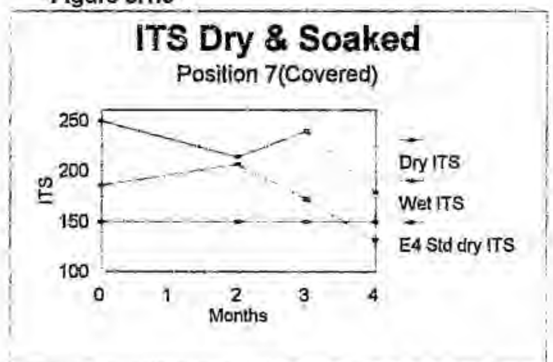
Material : Foam Stabilised Sand
Figure 5.1.7



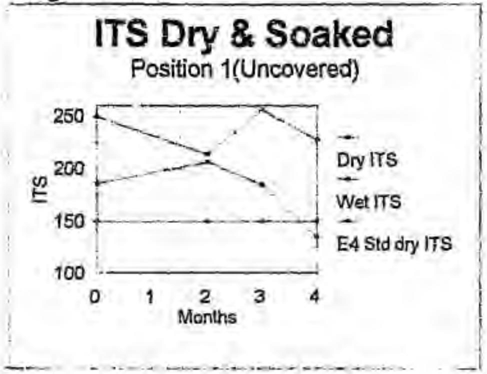
Material : Foam Stabilised Sand
Figure 5.1.8



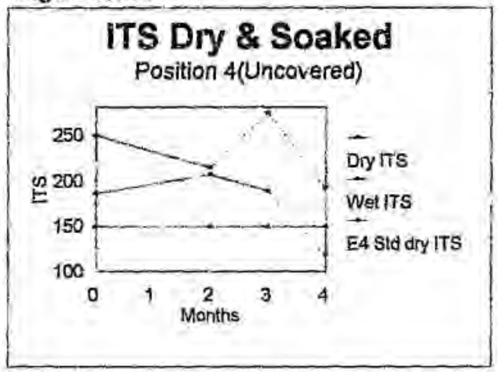
Material : Foam Stabilised Sand
Figure 5.1.9



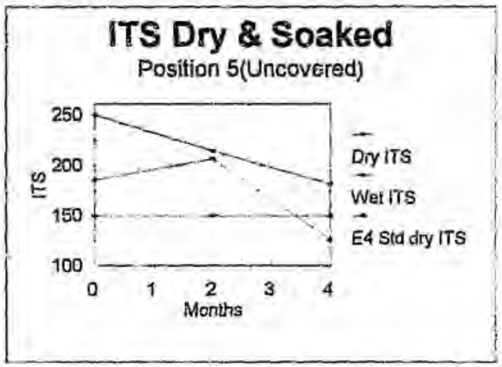
Material : Foam Stabilised Sand
Figure 5.1.10



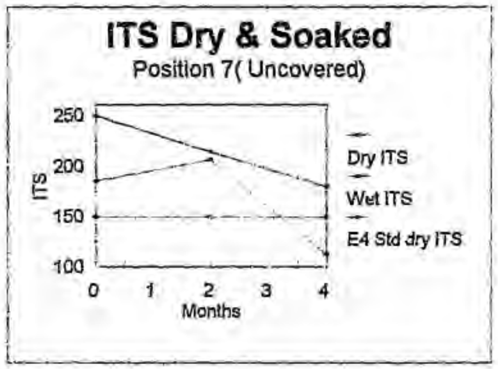
Material : Foam Stabilised Sand
Figure 5.1.11



Material : Foam Stabilised Sand
Figure 5.1.12



Material : Foam Stabilised Sand
Figure 5.1.13



5.1.5 Conclusions

The analysis was limited because only a single sample was tested at months 0 and 2. However certain trends were evident.

Effect of Stockpiling on Bulk Relative Density:

a) There was an increase of the B.R.D with time for all the positions tested as well as for both the covered stockpile scenario and the uncovered stockpile scenario [figure 5.1.4 and Figure 5.1.5]. The B.R.D seems to reach its climax after about 3 months, after which it stabilises.

b) The material that was covered shows no significant difference from the material that was uncovered [Appendices E.1]

c) The material sampled from the outer surface of the stockpiled material did not have any significant difference to the material sampled from within the stockpile [Appendices D.1].

d) At level of significance of 5%, the material shows no significant decrease or increase in the B.R.D over the four (4) month period that the tests were carried out over. [Tables 5.1.4.1a and b]

Dry Indirect Tensile Strength

a) The Foam stabilised sand shows no significant improvement / decrease of the I.T.S on covering the material. [Appendices E.1]

b) The surface samples and the inner samples showed no significant difference [Appendices D.1]

c) The graphs shown in Figures 5.1.6 to 5.1.9 show that the material having been prepared in month 0, and exhibiting the shown characteristics, on covering after two months (when material was moved to stockpile in Durban) improved on its dry ITS before it showed signs of weakening in the fourth month.

The graphs in Figures 5.1.10 to 5.1.13 (uncovered stockpile) show a mixture of improvements before month 4 and a rapid decline at positions 5 and 7.

The interesting thing to note is that in all cases the dry ITS remained well above the 150kPa required for the higher trafficked roads.

d) The statistical analysis on table 5.1.4.2 a and b shows that at level of significance of 5% the variation of strength over the four months was not significant.

Soaked Indirect TensileStrength

a) The Figures 5.1.6 to 5.1.13 show that from the time the material was stockpiled (month 2) the soaked ITS deteriorated at a more rapid rate than the corresponding dry ITS.

b) Again the analysis of Appendices E.2 and D.2 shows no significant difference between the inside of the stockpile and the outside nor between the covered and uncovered material.

c) Tables 5.1.4.3 a) and b) show no significant variations in the soaked ITS over the four-month period for both the uncovered and covered material.

Retained Indirect Tensile Strength

a) As the graphs 5.1.6 to 5.1.13 show the soaked ITS decreasing at a faster rate than the dry ITS, the retained ITS is less at the beginning and becomes larger at the end as the dry ITS values start to decrease.

b) The ANOVA (analysis of variance) in Table 5.1.5a shows that there is no significant variation in the results obtained for the uncovered material over the duration of the experiment.

The Table 5.1.4.4b shows however that there is a significant variation between the top (position 7), middle (position 4) and bottom (position 1) of the covered stockpile. This implies that at least one of the positions does not have the same mean retained ITS as the other positions.

c) Appendices D.2 shows that there is no significant difference between the retained ITS on the surface samples and the samples from within the stockpile.

d) Appendices E.2 shows that there is a significant difference between the covered material and the uncovered material as far as the Retained ITS is concerned.

General

The workability of the stabilised material was found to be very similar to the unstabilised material. Therefore the stabilised sand material can be expected to have the same productivities with labour based construction as for the unstabilised material (refer to chapter 2.7).

5.2. Foam Stabilised RAP

5.2.1 Designed Parameters

Aggregate

The aggregate consisted of a mixture of 85% RAP from Colas in Durban and 15% crusher dust from the Ridgeway Quarry in Durban. Refer to Appendix B for the moisture density of the material.

Foamed RAP Mixture

Refer to the Appendix B for the detailed design options considered. Below is a table showing the option adopted for the material.

Table 5.2.1: Foam Stabilised RAP: Design

Binder content	Moisture Content	Bulk Rel. D	Soaked ITS	Dry ITS	Retained ITS	Dynamic Creep	Resilient Mod.
6.3%	3.3%	2.131	365KPa	573	63.9%	38.2MPa	4140
6.6%	3.2%	2.123	350	538	65.1%	39.4	4118

Note : Fill area represents the adopted design
Mod AASHTO was 2125Kg/m3
Optimum moisture content was 5.2%

5.2.2 Parameters Investigated: Stockpile life.

The test programme was carried out on one large stockpile in Durban foamed in March 1997. The material was placed in a conical shape as the typical section (refer to section 5.1. 4) depicts, and material was sampled from May 1997 (2 months old) for testing. The material was very hard even from the beginning and working the material proved to be difficult as a pick was required to sample the material. A shovel would not even penetrate the material.

Table 5.2.2 Foam Stabilised RAP: Workability

Material : Recycled Asphalt (RAP)		
POSITION	**Shovel penetration**	**Worker's Opinion**
Top 500mm deep	No penetration	Hard pickable material
Side 500mm inside	No penetration	Hard pickable
Surface 100mm	No penetration	Hard pickable

Note: The results are true for the duration of the testing programme.

5.2.3 Test Results

The testing programme was designed as for the foamed sand, the difference being that this stockpile was left completely uncovered. The results obtained are shown bel [illegible]w.

Test Results: Month 2

Table 5.2.3.1: Foam Stabilised RAP: Result Month 2

Position	1	4	5	7	RT
M/content	2.9	3.5	4.9	3.4	3.9
B/content	6.6	6.5	7.1	7.8	5.8
B.R.Density	2.061	2.066	2.081	2.167	2.052
Dry ITS	471	562	[illegible]73	561	493
Wet ITS	420	441	505	409	395
Retained	89.2	78.5	88.1	72.[illegible]	80

Note : The quoted moisture co[illegible] are the natural moisture contents

RT represents foamed [illegible] that was treated with 1% of 30% emulsion.

Test Results: Month 4

Table 5.2.3.2: Foam Stabilised RAP: Month 4

Position	1	4	5	7
M/content	1.8	1.6	3.1	3.4
B/content	-	-	-	-
B.R.Density	-	-	-	-
Dry ITS	581	572	377	516
Wet ITS	466	411	406	397
Retained	80.2	71.9	107.7	76.9

Test Results: Month 5

Table 5.2.3.3: Foam Stabilised RAP: Month 5

Position	1	4	5	7
M/content	3.2	3.4	4	4
B/content	-	-	-	-
B.R.Density	2.04	2.065	2.057	2.054
Dry ITS	556	556	591	498
Wet ITS	369	490	401	501
Retained	66.3	88.1	67.9	100.6

Test Results: Month 6

Table 5.2.3.4: Foam Stabilised RAP: Month 6

Position	1	4	5	7
M/content	3.3	1.1	4.5	4.1
B/content	6.4	7.2	5.8	6.6
B.R.Density	2.05	2.038	2.066	2.049
Dry ITS	472	301	375	511
Wet ITS	383	247	324	418
Retained	81.14	82.1	86.4	81.8

5.2.5 Statistical Analysis

Table 5.2.5.1 Bulk Relative Density

Time (Months)	Position 1	Position 4	Position 7	Position 5
2	2.061	2.066	2.167	2.081
5	2.04	2.065	2.054	2.057
6	2.05	2.038	2.049	2.066

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	6.294	2.098	0.003577
Row 2	3	6.159	2.053	0.000157
Row 3	3	6.137	2.045667	4.43E-05
Column 1	3	6.151	2.050333	0.00011
Column 2	3	6.169	2.056333	0.000252
Column 3	3	6.27	2.09	0.004453

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.004818	2	0.002409	2.00157	0.249804	6.944276
Columns	0.002743	2	0.001371	1.139599	0.4058	6.944276
Error	0.004814	4	0.001203			
Total	0.012374	8				

Table 5.2.5.2 Dry Indirect Tensile Strength

Time (Months)	Position 1	Position 4	Position 7	Position 5
2	471	562	561	573
4	581	572	516	377
5	556	556	498	591
6	472	301	511	375

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	1594	531.3333	2730.333
Row 2	3	1669	556.3333	1240.333
Row 3	3	1610	536.6667	1121.333
Row 4	3	1284	428	12477
Column 1	4	2080	520	3240.667
Column 2	4	1991	497.75	17248.25
Column 3	4	2086	521.5	751

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	29996.92	3	9998.972	1.779027	0.250952	4.757055
Columns	1415.167	2	707.5833	0.125894	0.883977	5.143249
Error	33722.83	6	5620.472			
Total	65134.92	11				

Table 5.2.5.1 shows that the F-values for the rows and the columns are below the critical F-values of 6.944276. This means that there is no significant variation in the bulk relative density in terms of the position of the test and in time, at the 0.05 significance level.

Table 5.2.5.2 shows that the F-values for the rows and the columns are below the critical F-values of 4.757055 and 5.1432 respectively. This means that there is no significant variation in dry ITS in terms of the position of the test and in time, at the 0.05 significance level.

Table 5.2.5.3 Wet ITS

Time (Months)	Position 1	Position 4	Position 7	Position 5
2	420	441	409	505
4	466	411	397	406
5	369	490	501	401
6	383	247	418	324

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	1270	423.3333	264.3333
Row 2	3	1274	424.6667	1330.333
Row 3	3	1360	453.3333	5364.333
Row 4	3	1048	349.3333	8160.333
Column 1	4	1638	409.5	1881.667
Column 2	4	1589	397.25	11093.58
Column 3	4	1725	431.25	2236.25

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	17768	3	5922.667	1.275223	0.364652	4.757055
Columns	2372.167	2	1186.083	0.255378	0.782635	5.143249
Error	27866.5	6	4644.417			
Total	48006.67	11				

Table 5.2.5.4 Retained ITS

Time (Months)	Position 1	Position 4	Position 7	Position 5
2	89.2	78.5	72.9	88.1
4	80.2	71.9	76.9	107.7
5	66.3	88.1	100.6	67.9
6	81.14	82.1	81.8	86.4

Anova: Two-Factor Without Replication

SUMMARY	Count	Sum	Average	Variance
Row 1	3	240.6	80.2	68.59
Row 2	3	229	76.33333	17.46333
Row 3	3	255	85	301.33
Row 4	3	245.04	81.68	0.2412
Column 1	4	316.84	79.21	90.39107
Column 2	4	320.6	80.15	45.93
Column 3	4	332.2	83.05	150.1367

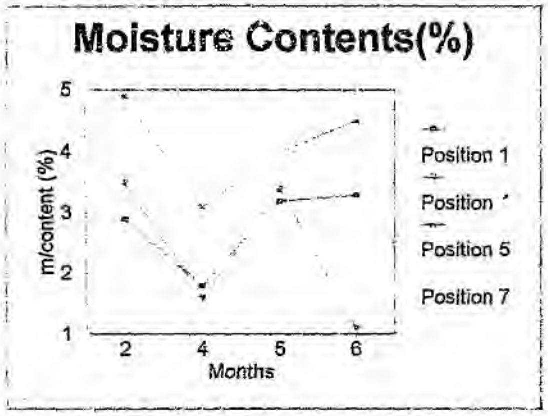
ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	116.1764	3	38.72547	0.31264	0.816113	4.757055
Columns	32.05227	2	16.02613	0.129383	0.881024	5.143249
Error	743.1968	6	123.8661			
Total	891.4255	11				

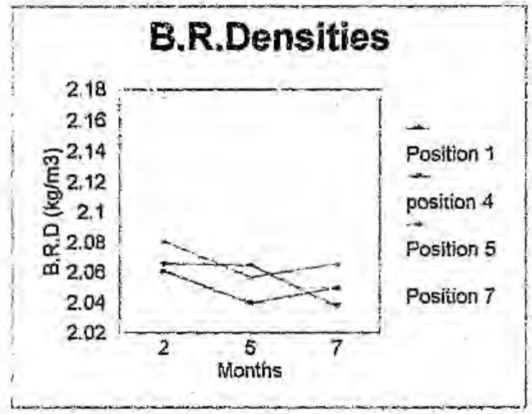
Table 5.2.5.3 shows that the F-values for the rows and the columns are below the critical F-values of 4.757055 and 5.1432 respectively This means that there is no significant variation in the soaked ITS in terms of the position of the test and in time, at the 0.05 significance level.

Table 5.2.5.4 shows that the F-values for the rows and the columns are below the critical F-values of 4.757055 and 5.1432 respectively. This means that there is no significant variation in the retained ITS in terms of the position of the test and in time, at the 0.05 significance level.

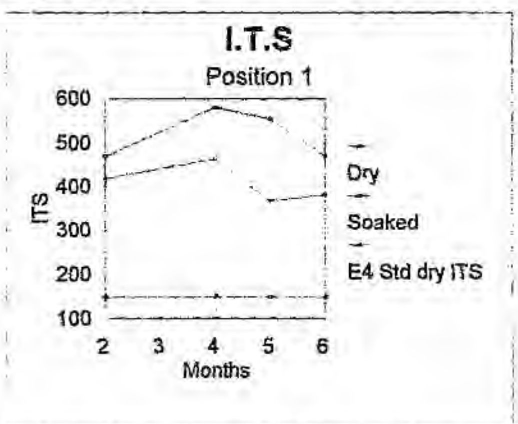
Material : Foam Stabilised RAP
Figure 5.2.1



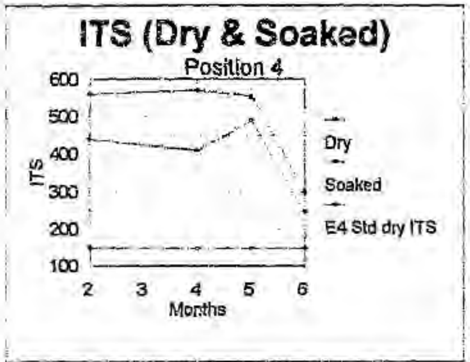
Material : Foam Stabilised RAP
Figure 5.2.2



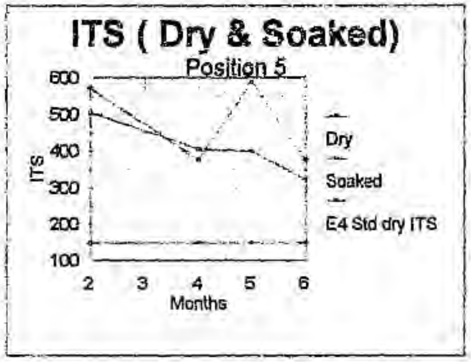
Material : Foam Stabilised RAP
Figure 5.2.3



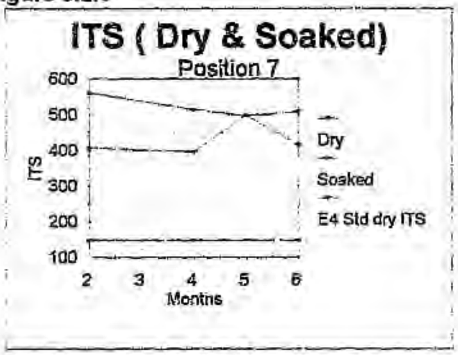
Material : Foam Stabilised RAP
Figure 5.2.4



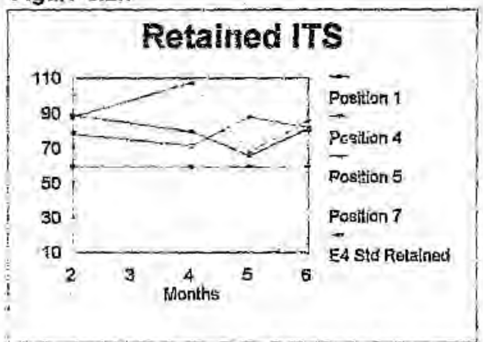
Material : Foam Stabilised RAP
Figure 5.2.5



Material : Foam Stabilised RAP
Figure 5.2.6



Material : Foam Stabilised RAP
Figure 5.2.7



5.2.5. Conclusions

a) Bulk Relative Densities: The B.R.D shows generally low variation over the duration of six (6) months, except for the single wayward second month result for position 7. The low variability may be attributed to the largeness of the particles and the hardness of the material in the recycled asphalt (RAP) which makes it difficult to compact. The Table 5.2.5.1 shows no significant variation from bottom to top of the stockpile and nor is there any significant variation over time.

b) The dry ITS: this parameter remained high for the first 5 months before it showed signs of decreasing [Figures 5.2.3 to 5.2.6]. In comparison to the required dry ITS the material showed no significant deterioration. Table 5.2.5.2 shows no significant variation in the positions tested as well as over time.

c) The Soaked ITS: this did not exhibit any significant decrease in the first four (4) to five (5) months and seemed to follow the general behaviour of the dry ITS. Again Table 5.2.5.3 shows no significant variation with position of test nor with time.

d) The retained ITS remained well above the 60% required for E4 traffic over the duration of the experiment. The result for month 4 on position 5 seems to be inconsistent. [Refer to Table 5.2.5.4 for proof of insignificance of position of test and time in stockpile]

e) Appendices F.1 and F.2 shows no significant difference between the surface and the inside of the stockpile for the B.R.D, the dry ITS, the Soaked ITS and the Retained ITS.

5.3 SOWETO FOAM STABILISED GRAVEL

5.3.1 Designed Parameters

Aggregate:

The Soweto material was a red weathered chert gravel material. A number of tests were carried out on this material and these include the following:
The California Bearing Ratio (CBR) and the Marshall test for the foamed bitumen design. Refer to Appendices C for details.

Foamed Gravel Mixture

An initial design was done in August 1994 and the red weathered chert showed some good results as far the soaked stability was concerned giving an average value of 12.2kN (refer to Appendices C, test dated 20/8/94)

Further tests on the material were done in October 1995 and these surprisingly gave poor results for the retained Marshall Stability at values less than 4.0kN.
The final tests were done in January 1996 and the material was mixed with some quartz material less than 40mm in size. The design alternatives considered are given in detail in Appendix C.

To ensure that the strength of the material was measured at the same moisture content for comparison purposes , the moisture density relationship of the foamed material was investigated and all tests done were at the optimum moisture content of 10.7%. (Refer to Appendix D)

An extract of the design is shown below.

Table 5.3.1

Mix No_	Binder Content	m/c	B.R.D	Marshall Stability (Dry)	Marshall Stability (Wet)	Retained Stability
1	4.0%	9.6%	2.038	25.2kN	7.2kN	28.6%
2	4.4	9.2	2.048	23.1	14.0	60.6

Sample 1: This sample had gravel and no quartz was added.

Sample 2: This sample was gravel with some 37.5mm quartz material added

The stability requirements for E0 to E2 traffic are minimum dry stab. of kN.

5.3.2 Parameters Investigated:

The material was foamed in June 1996 and was stockpiled for a year before testing was carried out on the material. Some of the material was bagged after it had spent six months in stockpile. Both the bagged material and the material in stockpile were tested after a year (June 1997). The materials were tested by means of the Indirect Tensile Strength (ITS) tests and the aim was to determine whether the stockpile material showed deferential deterioration in properties between the material at the surface of the stockpile and that in the middle of the stockpile. It was also the aim of the experiments to determine whether the bagged material had better physical properties than the material in stockpile.

It should be noted however that despite the fact the foam stabilised gravel had been in stockpile for over a year it could still be penetrated with a shovel and was as workable as the unstabilised gravel in the area.

5.3.3 Test Results

Table 5.3.2.1: Month 12:

Where Tested	Moisture Content		Binder Content		Bulk Rel. Density		Dry ITS		Wet ITS		Retained ITS	
	a	b	a	b	a	b	a	b	a	b	a	b
1m from top.	11.2	10.7	3.2	3.2	2.03	2.05	415	364	*	*	-	-
500mm into side	11.8	10.7	2.4	2.4	2.04	2.05	427	393	*	*	-	-
100mm surface	6.1	10.7	2.9	2.9	1.86	2.03	159	339	*	*	-	-
Surface Disturbed	6.0	10.7	3.2	3.2	1.85	2.01	82	405	*	*	-	-
Bagged	14.9	10.7	5.8	5.8	1.93	1.97	258	237	*	*	-	-

a represents natural parameter as sampled in stockpile

b represents the parameter measured at optimum moisture content.

* indicates that the sample collapsed.

Table 5.3.2.2: Month 13: Correlation between ITS and Marshall

	Moisture content	Binder content	B.R. [illegible]	Dry ITS	Dry Stability	Wet ITS	Retained ITS
500mm into side	12.6	---	---	386	29.5	*	---
100mm of surface	6.7	---	---	345	29.1	*	---
Bagged	---	---	---	432	26.5	*	---

* indicates that sample collapsed
Moisture content recorded is the natural moisture content.
Other parameters were tested at O.M.C

5.3.4 Conclusion

a) The foam stabilised gravel was very variable as indicated by the fact that the design done on the material in 1994 gave good results and yet the same material gave poor results when tested a year later. The addition of quartz material to the mixture had the effect of improving the retained stability of the material.

b) The effect of bringing the moisture content to O.M.C seems to be that of improving the properties of the material, whether or not the original/ natural moisture content was above or below the O.M.C [Table 5.3.2.1]

c) When the material is in its natural state it appears as though the outer/surface material is drier than the inne[illegible]terial (eg the moisture content for the surface disturb[illegible] material was 6% an[illegible]e material one metre within the stockpile was 11.2%). The tests done at [illegible] state show that the material on the surface of the stockpile is inferior to the [illegible] within the stockpile. On bringing the moisture content to o.m.c the properties [illegible] material become more uniform.

d) Bagging of the material does not improve the properties of the material.

e) Tests done in the thirteenth month show that the dry Marshall stability remains high even after 13 months in stockpile and that the material fails due to lack of strength when soaked. [Note that the designed dry Marshall stability was 23.1kN and the dry stability at the thirteenth month was greater than this value].

5.4 Rejuvenation of Foamed Bitumen on Addition of Emulsion

5.4.1 Effect on Foam Stabilised Gravel Material

The results shown above (Tables 12 and 13) clearly indicate that the foamed gravel was beyond usefulness according to the criteria for the design of foamed bitumen. As a trial solution engineers have been using emulsions to 'restore' the foamed bitumen stabilised materials to acceptable levels.

To determine whether the material could be restored to acceptable properties, 1% of a 30% bitumen emulsion was added to the material and then the material was retested to check for any improvements. The following results were obtained:

Table 5.4.1 Effect of Adding Emulsion to Foam Stabilised Material.

Test Done	500mm into Side		Bagged Material	
	Normal	Add Emulsion	Normal	Add Emulsion
Moisture Content	10.7	10.7	10.7	10.7
Dry ITS	386	335	432	319
Soaked ITS	Collapsed	Collapsed	Collapsed	Collapsed
Retained ITS	---	---	---	---

5.4.2 Effect on Recycled Asphalt Material

The problems faced by workmen, in labour intensive jobs, is mainly that of workability of a material. A material that hardens quickly makes it extremely difficult for workmen to handle it. Although foamed RAP material does last for a long time in excess of six months as demonstrated by the results in this project, it has the disadvantage of hardening quickly. It was of interest to try and determine the effect of adding 1% of 30% emulsion to the material and remixing, i.e. to determine whether the material would be rejuvonated in strength and workability.

The test results have been shown in section 5.2.3 in Table 5.2.3.1(shown below) and the following deductions have been made from the results.

Table 5.4.2: Effect of Emulsion on Foam Stabilised RAP.

Position	1	4	5	7	RT
M/content	2.9	3.5	4.9	3.4	3.9
B/content	6.6	6.5	7.1	7.8	5.8
B.R.Density	2.061	2.066	2.081	2.167	2.052
Dry ITS	471	562	573	561	493
Wet ITS	420	441	505	409	395
Retained	89.2	78.5	88.1	72.9	80

Note : The quoted moisture contents are the natural moisture contents

RT represents foamed RAP material that was treated with 1% of 30% emulsion.

5.4.3 Conclusions

a) The addition of emulsion did not regenerate the foam stabilised gravel that has been stockpiled for too long. This was inspite of the fact that moisture contents had been adjusted before testing to take into account the extra moisture from stabilisation.

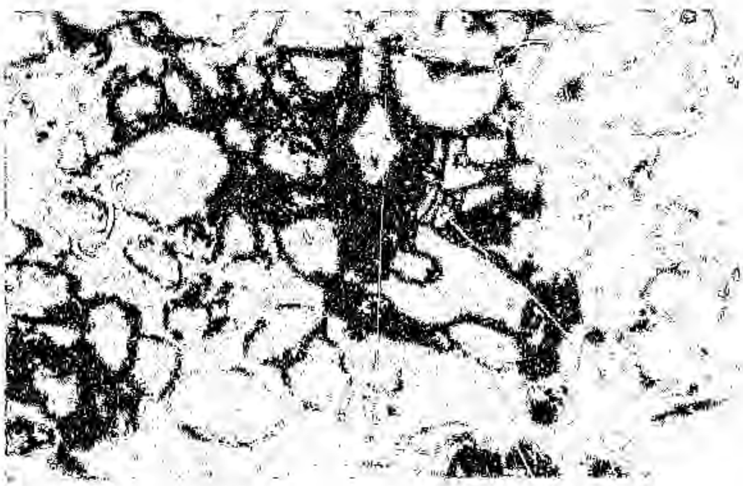
b) The effect of adding the emulsion seems to be that of decreasing the dry stability while the corresponding decrease in the soaked stability is not as pronounced, leading to a situation where the retained strength/stability of the material is increased. This would be useful in a situation where both the dry ITS and the soaked ITS are above the specified levels and yet the retained strength/stability is not meeting the requirements.

Note. No microscopic analysis was done on the emulsion stabilised material to determine the effect of the emulsion on the granular make up of the material.

5.5 Microscopic Analysis

The materials sampled were also examined under the microscope to determine how the materials were coated with bitumen as well as to determine whether there were any differences in the structure of the material which contributed to the different properties of the materials.
Thin sections were made and then these were analysed and representative photographs were taken and these are shown below.

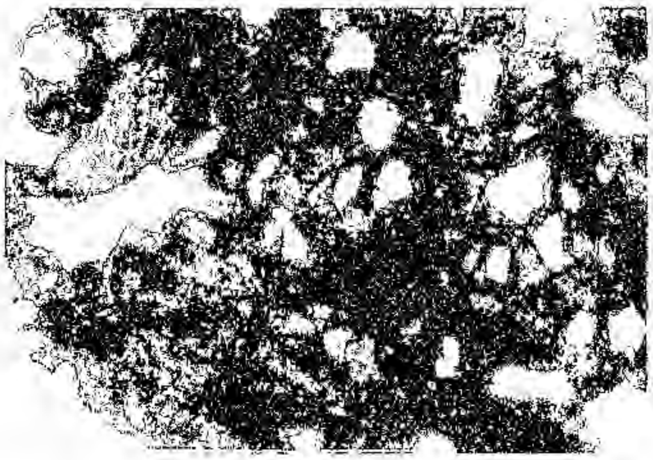
Foam Stabilised Recycled Asphalt Material (RAP)



This shows relatively low bitumen content covering the light coloured quartz material. It appears the bitumen covers both the small particles and the larger forms globules in the open spaces (voids).

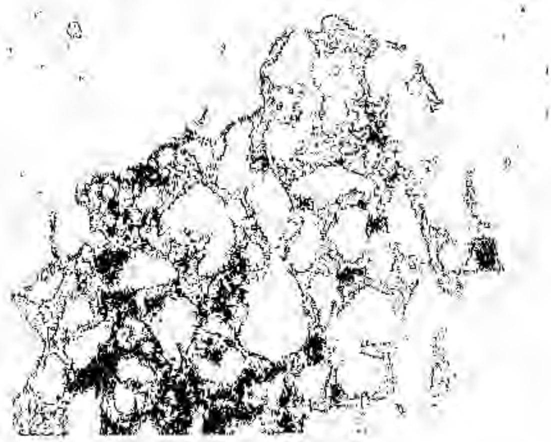
Foam Stabilised RAP

This photograph shows an area that has a abundance of bitumen. The quartz material is still covered with a thin layer of bitumen but the rest of the bitumen is in the voids.



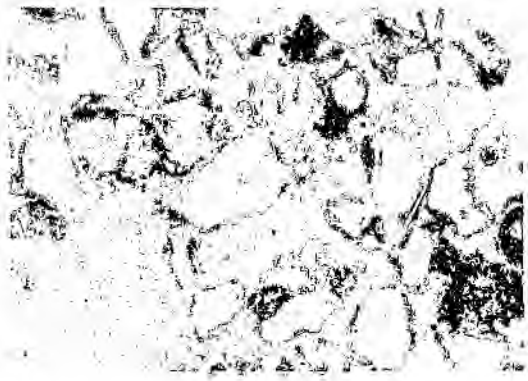
Foam Stabilised Sand ex-Duku Duku

The photograph shown below shows a well structured matrix of the quartz material bound together by bitumen.



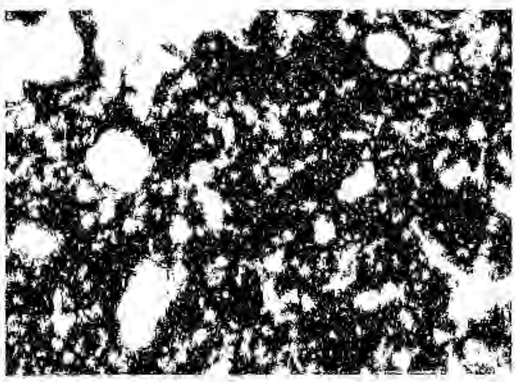
Foam Stabilised Sand ex-Duku Duku

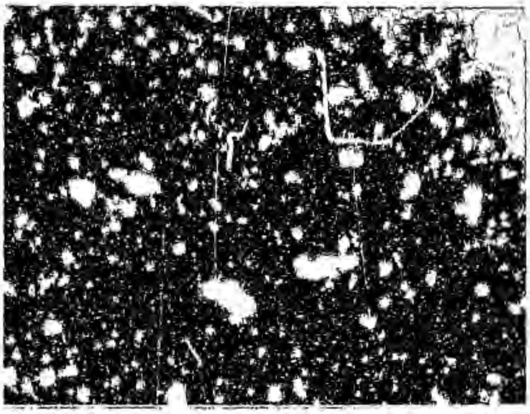
This photograph shows a low bitumen content area with mainly a thin layer of bitumen coating the quartz material.



Foam Stabilised Gravel

The photographs here show a variation from low bitumen content per unit area to larger bitumen content areas. In all cases the bitumen covers the quartz material and also forms globules in the voids.





The above set of photographs were taken randomly from their respective stockpiles and the great variability shows that the bitumen does not cover the aggregate uniformly. There is variation from well structured matrices of bitumen and aggregate to not so well structured systems.

6.0 Conclusion and Recommendations

- The South African experience with foam stabilised material [refer to Section 3.3.2: Tables 3.3.2.2 and 3.3.2.3] showed that weathered granitic material when foam stabilised does not show a significant decrease in the dry stability over a two month period. The sample showed a marginal decrease in dry stability from 13.7kN to12.5kN. The soaked strength on the other hand, was reduced significantly from an initial value of 11.3kN to 7.3kN. This decreased value of soaked stability is responsible for the big decrease in retained stability. The RAP material showed better results as far the soaked stability was concerned.

- The Soweto project showed that the foam stabilised material was sensitive to whether or not the aggregate had quartz material in it (refer to Appendix C). The possible reason for the poor results in the Soweto gravel could be that the quartz content was variable and since the initial results were poor it can not be concluded that the foam stabilised gravel failed after a year in stockpile due to degradation alone.

- This study shows that foam stabilised material when properly designed, can last for over four months (foamed sand) or even six months (foam stabilised RAP) while still exhibiting good dry and soaked stabilities.

- The only possible cause of deterioration in the properties of foam stabilised material, is the decrease in soaked strength/stability which will ultimately result in the collapse of the material when soaked. This is shown in the Soweto Foam stabilised gravel where the material retained its dry stability even after 13 months in the stockpile. The retained strength was non existent due to the poor soaked strength. This seems to suggest that the soaked strength is low due to a weak bond between the bitumen and the aggregate. Further research is recommended to determine why the soaked stabilities decrease at a faster rate than the corresponding dry stabilities.

- The results have shown that there is no significant difference between the different positions in the stockpile ie whether the material was taken from the top, middle or bottom of the stockpile or from the surface or from within the stockpile. The implications here are that the material will not require any special costly stockpiling methods or methods. This would suit labour intensive construction well.

- An aspect that was investigated in this study was the possibility that the foam stabilised material foams a protective layer/crust which ensures that the inside material remains in good condition. The results of the moisture contents and strength tests showed that there was no significant difference between the outer 150mm and the inside of the stockpile. The material will not require covering nor bagging as the difference this would make is not worth the extra cost.

- There is the possible commercial benefit that the 'manufacturing' of the foam mix can be done well before the project starts without the fear that a delay in the project start time will affect the material negatively. The material may also be bagged and sold to clients whose jobs can start four months after the purchase date of the material.

- The biggest advantage is that the foam stabilised material will be as workable as the neat aggregate material before stabilisation i.e. an aggregate that is workable when it has not been stabilised, like the Soweto gravel and Duku Duku sand will be workable after stabilisation. A material like reclaimed asphalt on the other hand is workable for a short period of time when unstabilised and consequently it becomes harder to handle a short period after stabilisation. This means that all workable materials such as sands and poor gravels would lend themselves well to labour intensive construction.

- The fact that the foam stabilised materials will last for over four months in stockpile and that they do not need additional expensive storage conditions like covering e.t.c. implies that the planning of labour resources can be done without having to rush the job. This could result in better quality roads.

- The material properties are improved by bringing the material to O.M.C before compaction and testing. This is in accordance with normal engineering practice.

APPENDICES

APPENDIX A: Ma .)esign of Duku Duku Sand

BITUTEK LABORATORY (PTY) LTD

Registration Number 79/01593/07

16 April 1997

Colas East (Pty) Ltd
P O.Box 12373
Jacobs
4026

<u>Attention Mr Steve Nel</u>

Dear Sir

Dukuduku Foam Design   JC 1659

We refer to report JC1644 that was conducted on two samples of sand from the above mentioned project that were delivered to our laboratory, on your behalf by Shires, for a foam asphalt design.

Attached please find the two-page mix design ,incorporating the previous work as well as one point with 1% cement added as requested by yourselves.

The bitumen used was a 150/200 pen ex SAPREF.

Care should be taken regarding lumps in the berea red sand.

We wish to thank you for your support and should you require any further information please feel free to contact us.

Yours faithfully

C.H.Loots
Manager

25 Westmead Road, Pinetown 3600 P O Box 15324 Westmead 3608 South Africa

BITUTEK LABORATORY (PTY) LTD

FOAM ASPHALT MIX DESIGN

Client : Colas East (Pty) Ltd — JC No : 1659

Job : Dukuduku — Date : 2/4/97

Mix Tipe: Blend of Sands

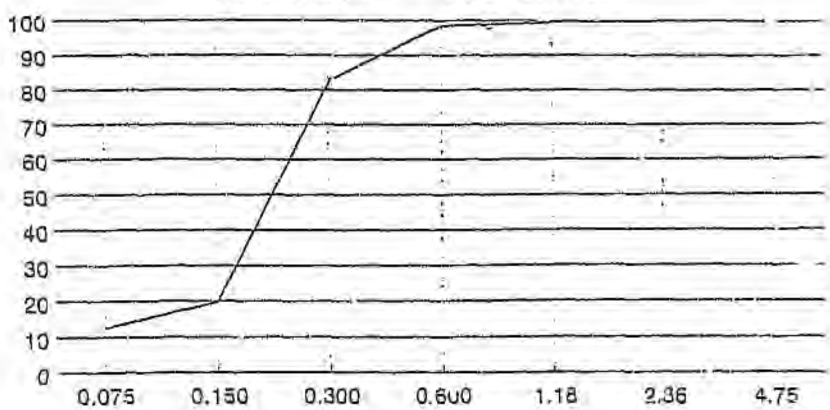
AGGREGATES

SAMPLE NO	NOMINAL SIZE	DESCRIPTION AND SOURCE
1	Sand A	Dune Sand ex Dukuduku
2	Sand B	Berea Red Sand ex Dukuduku

SIEVE ANALYSIS % PASSING

SAMPLE NUMBER	1	2	THEO.	DESIGN MIX
% IN MIX	75.0	25.0	COMBINED	SPEC.
SIEVE SIZE (mm)			GRADING	
37.5				
26.5				
19.0				
13.2				
9.5				
6.7				
4.75				
2.36	100	100	100.0	
1.18	100	100	99.8	
0.600	99	97	98.5	
0.300	82	84	82.7	
0.150	13	43	20.4	
0.075	5.6	32.9	12.4	

SIEVE SIZE (MM) – TO LOG SCALE



BITUTEK LABORATORY (PTY)LTD

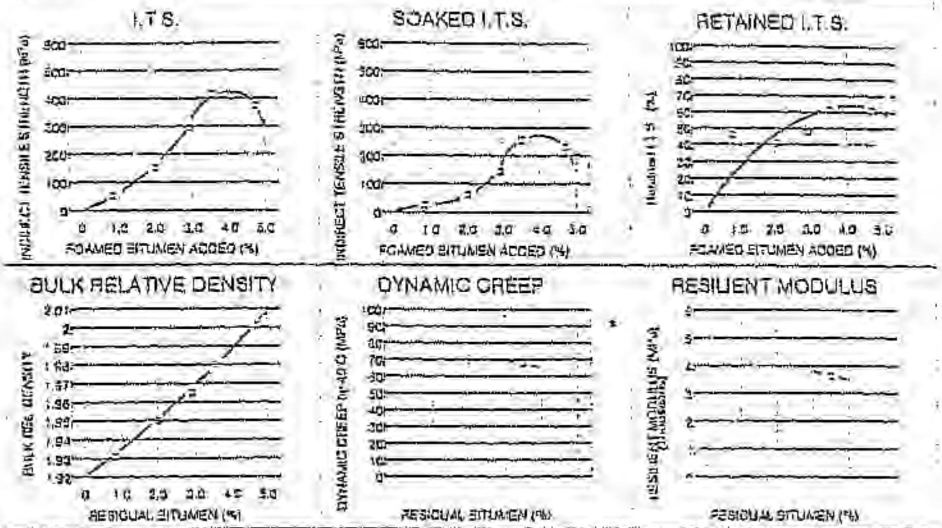
FOAM ASPHALT STABILISATION

CLIENT : Colas East (Pty) Ltd — JC No : 1659

JOB : Dukuduku — DATE : 02/04/1997

AGGREGATE : Berea Red 25 % . Dune Sand 75% — REF : JC1644

BITUMEN : 150/200 EX SAPREF



MIX NUMBER	1%	2%	3%	4%	5%	3.3%
BITUMEN CONTENT (%)	0.8	2.0	2.9	3.5	4.7	3.4
CEMENT CONTENT (%)			0			1.0
MOISTURE CONTENT (%)	8.3	8.2	8.3	8.3	7.9	8.6
BULK RELATIVE DENSITY	1.931	1.950	1.965	1.980	2.001	1.985
SOAKED I.T.S. (kPa)	24	61	142	256	229	196
I.T.S. (kPa)	52	150	295	415	374	329
RETAINED I.T.S. (%)	46.2	40.7	48.0	61.7	61.2	59.5
DYNAMIC CREEP MODULUS (MPa)				88.0		100.5
RESILIENT MODULUS (MPa)				3816		3743
MOD AASHTO (kg/m³)			1868			
OMC – (MOD AASHTO) (%)			9.3			
OPTIMUM MOISTURE CONTENT (%) *			8.4			

* 90% OF OMC AT MOD AASHTO COMPACTION EFFORT

BITUTEK LABORATORY (PTY) LTD
Registration Number 79/02693/07

20 August 1996

Colas East (Pty) Ltd
P.O.Box 12373
Jacobs
4026

Attention Mr Steve Nel

Dear Sir

Foam Asphalt Mix Design - Dukuduku JC 1342

We refer to the foam asphalt mix design conducted on a blend of sand samples from the above mentioned project.

Attached please find the foam asphalt mix design as well as the moisture density relationship of the mixture. The blend ratio was 60 % dune sand to 40 % berea red sand.

Special care are to be taken to prevent the incorporation of lumps originating from the berea red sand,

The repeated load testing was done using a Nottingham Asphalt Tester and the following test conditions:

Dynamic creep modulus

100 kPa, 40 °C, 30 pulses conditioning and then a further 3600 pulses at 0.5 Hz, square wave form.

Resilient modulus

120 ms rise time, 5μm horizontal deformation, 25 °C , assumed Poisson's ratio of 0,4.

We wish to thank you for your valued support and should you require any further information please feel free to contact us.

Yours faithfully

C.H.Loots
Manager

25 Westmead Road, Pinetown 3600 P O Box 15324 Westmead 3608 South Africa

SOILS DESIGN LABORATORIES (NATAL)

MOISTURE/DENSITY RELATIONSHIP

Client : Bitutek Job Card No.: 62136

Project : Duku-Duku O/NO. 4/30 Sample No. : 6640

Date : 14-08-96

Field/Pit No.: Material Description : Dk.Br.Fine Sand

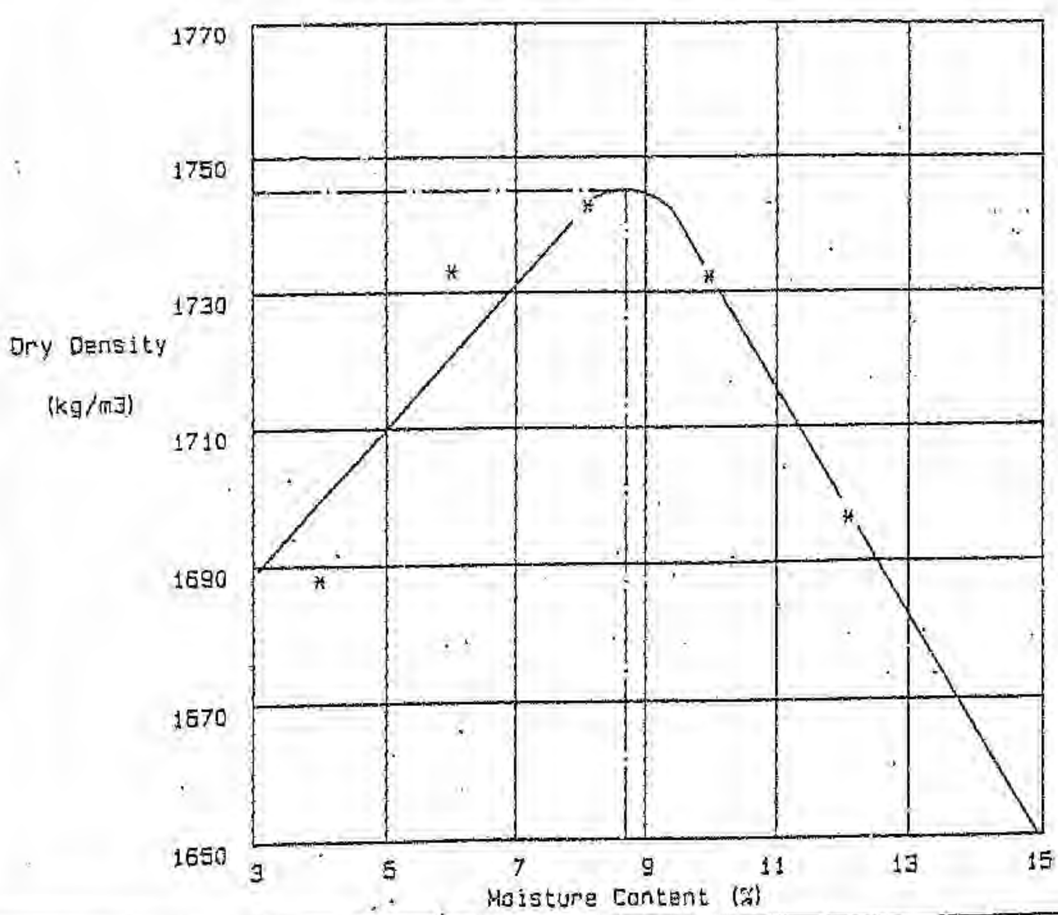
Position : 40:60 + Lt.Br.Dune Sand

Depth : Stabilising Agent : Natural

Moisture / Density Relationship

Nominal Moisture Content	(%)	4	6	8	10	12
Dry Density	(kg/m3)	1688	1733	1743	1732	1696
Moisture Content	(%)	4.0	6.0	8.1	10.0	12.1

MAXIMUM DRY DENSITY : 1745 kg/m3
OPTIMUM MOISTURE CONTENT : 8.7 %

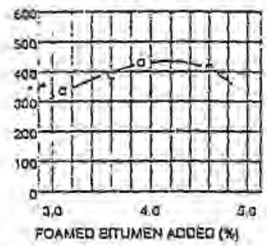


BITUTEK LABORATORY (PTY)LTD

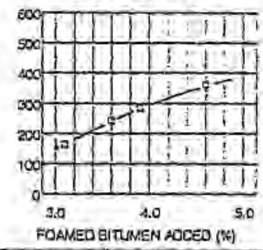
FOAM ASPHALT STABILISATION

CLIENT	: Colas East (Pty) Ltd	JC No :	1342
JOB	: Dukuduku	DATE :	20/08/1996
AGGREGATE	: Berea Red 40 % , Dune Sand 60%	CODE :	
BITUMEN	: 150/200 EX SAPREF		

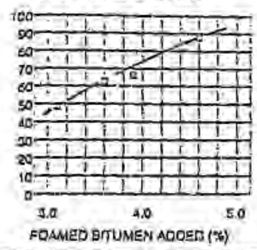
I.T.S.



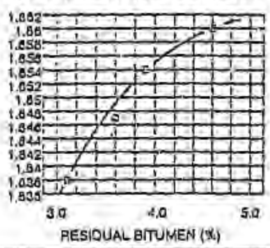
SOAKED I.T.S.



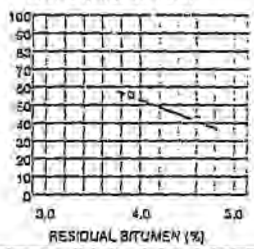
RETAINED I.T.S.



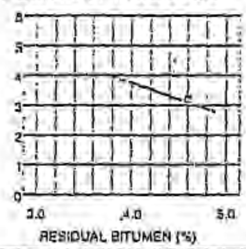
BULK RELATIVE DENSITY



DYNAMIC CREEP



RESILIENT MODULUS



MIX NUMBER	A	B	C	D			
BITUMEN CONTENT (%)	3.1	3.6	3.9	4.6			
MOISTURE CONTENT (%)	6.1	6.2	6.1	5.9			
BULK RELATIVE DENSITY	1.836	1.847	1.854	1.860			
SOAKED I.T.S. (kPa)	163	242	284	362			
I.T.S. (kPa)	334	385	430	413			
RETAINED I.T.S. (%)	48.8	62.9	66.0	87.7			
DYNAMIC CREEP MODULUS (MPa)			55.7	42.0			
RESILIENT MODULUS (MPa)			3948	3195			
MOD AASHTO (kg/m³)	1745						
OMC – (MOD AASHTO) (%)	8.7						
OPTIMUM MOISTURE CONTENT (%)*	6.1						

* 70% OF OMC AT MOD AASHTO COMPACTION EFFORT

SOILS DESIGN LABORATORIES (NATAL)

ATTERBERG LIMITS TEST REPORT

Client : Bitutek Laboratory

Report Date : 1996:06:03

Project : B6610 - J.C.1336

Job Card No.: 62136

For the attention of: Mr H.Loots

TEST RESULTS

Laboratory Sample No.	6639		
Field No. / Position	B6610		
Material Description	Dk.Br. Soil Fines		
Stabilising Agent	Natural		
Liquid Limit %	20		
Plasticity Index %	6		
Linear Shrinkage %	3.0		

BITUTEK LABORATORY (PTY) LTD

Registration Number 79/02693/07

2 April 1997

Colas East (Pty) Ltd
P.O.Box 12373
Jacobs
4026

Attention Mr Steve Nel

Dear Sir

Dukuduku Foam Design JC 1644

We refer to the two samples of sand from the above mentioned project that were delivered to our laboratory, on your behalf by Shires, for a foam asphalt design.

Attached please find the two-page mix design as well as the Mod AASHTO optimum moisture content determination by SDLN.

The bitumen used was a 150/200 pen ex SAPREF. Please note that no lime or cement was used in the design. Care should be taken regarding lumps in the berea red sand.

We wish to thank you for your support and should you require any further information please feel free to contact us.

Yours faithfully

C.H.Loots
Manager

25 Westmead Road, Pinetown 3600 P O Box 15324 Westmead 3608 South Africa
Telephone: 031 - 700 4510 Fax: 031 - 700 3165
DIRECTORS: R M Dunbar P J Hechter A J N Lewis S J Emery* *Australian

SOILS DESIGN LABORATORIES (NATAL)

MOISTURE/DENSITY RELATIONSHIP

Client : Bitutek Laboratory — Job Card No.: 64770

Project : Oukuduku - Order No.4/81 — Sample No. : 8357

Date : 01-04-97

Field/Pit No.: — Material Description : Dk.Br.Sand

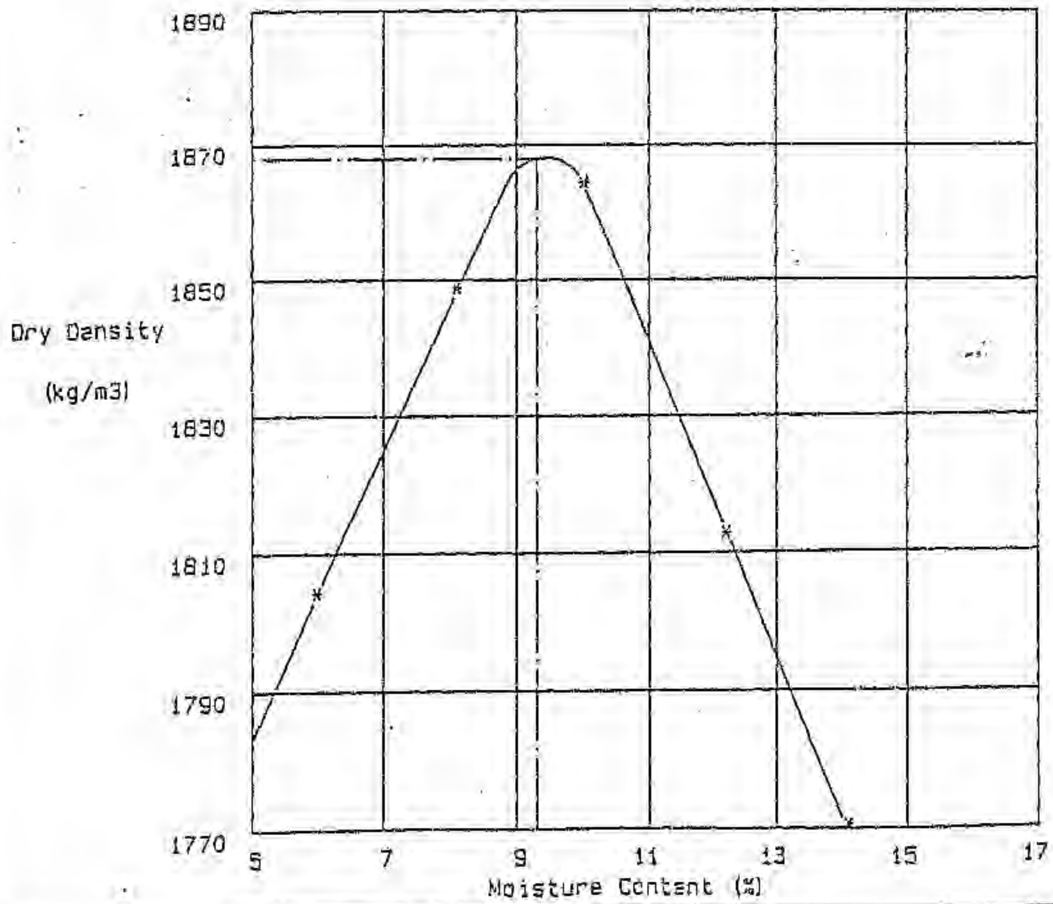
Position : (75:25)

Depth : — Stabilising Agent : Natural

Moisture / Density Relationship

Nominal Moisture Content	(%)	6	8	10	12	14
Dry Density	(kg/m3)	1804	1849	1864	1813	1771
Moisture Content	(%)	6.0	8.1	10.0	12.2	14.1

MAXIMUM DRY DENSITY : 1868 kg/m3
OPTIMUM MOISTURE CONTENT : 9.3 %



BITUTEK LABORATORY (PTY)LTD

FOAM ASPHALT STABILISATION

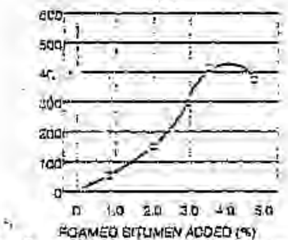
CLIENT : Colas East (Pty) Ltd JC No : 1544

JOB : Dukuduku DATE : 02/04/1997

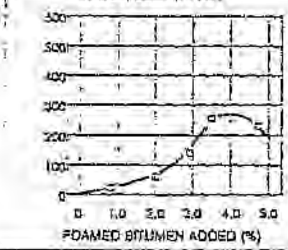
AGGREGATE : Berea Red 25 % , Dune Sand 75% CORE :

BITUMEN : 150/200 EX SAPREF

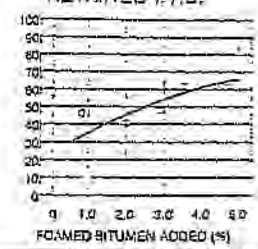
I.T.S.



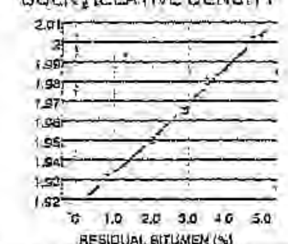
SOAKED I.T.S.



RETAINED I.T.S.



BULK RELATIVE DENSITY



DYNAMIC CREEP

RESILIENT MODULUS

MIX NUMBER	1%	2%	3%	4%	5%
BITUMEN CONTENT (%)	0.8	2.0	2.9	3.5	4.7
MOISTURE CONTENT (%)	8.3	8.2	8.3	8.3	7.9
BULK RELATIVE DENSITY	1.931	1.950	1.966	1.980	2.001
SOAKED I.T.S. (kPa)	24	61	142	256	229
I.T.S. (kPa)	52	150	296	415	374
RETAINED I.T.S. (%)	46.2	40.7	48.0	61.7	61.2
DYNAMIC CREEP MODULUS (MPa)				66.0	
RESILIENT MODULUS (MPa)				3816	

MOD AASHTO (kg/m³)	1868
OMC – (MOD AASHTO) (%)	9.3
OPTIMUM MOISTURE CONTENT (%)*	8.4

* 90% OF OMC AT MOD AASHTO COMPACTION EFFORT

E:TUTEK LABORATORY (PTY) LTD

FOAM ASPHALT MIX DESIGN

Client : Colas East (Pty) Ltd JC No : 1644

Job : Dukuduku Date : 2/4/97

Mix Tipe:

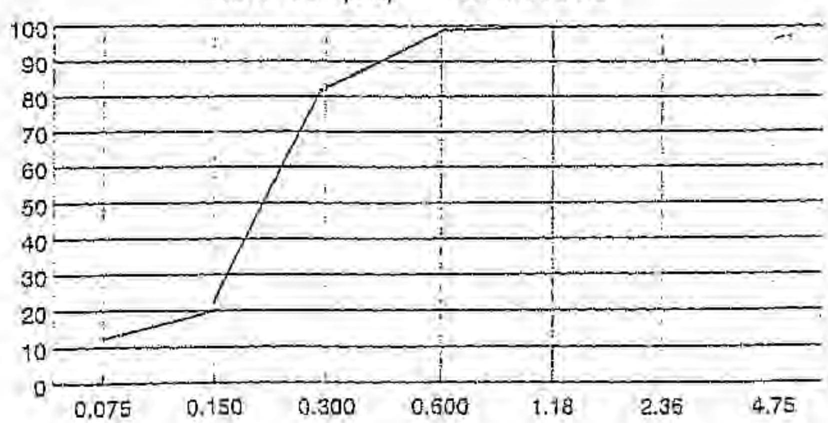
AGGREGATES

SAMPLE NO	NOMINAL SIZE	DESCRIPTION AND SOURCE
1	Sand A	Dune Sand ex Dukuduku
2	Sand B	Berea Red Sand ex Dukuduku

SIEVE ANALYSIS % PASSING

SAMPLE NUMBER	1	2			THEO.	DESIGN MIX
% IN MIX	75.0	25.0			COMBINED	SPEC.
SIEVE SIZE (mm)					GRADING	
37.5						
26.5						
19.0						
13.2						
9.5						
6.7						
4.75						
2.36	100	100			100.0	
1.18	100	100			99.8	
0.600	99	97			98.5	
0.300	82	84			82.7	
0.150	13	43			20.4	
0.075	5.6	32.9			12.4	

SIEVE SIZE (MM) — TO LOG SCALE



APPENDIX B

Material Design of Coedmore RAP and Soweto Sand

BITUTEK LABORATORY (PTY) LTD
Registration Number 79/02693/07

25 August 1996

Colas East (Pty) Ltd
P.O.Box 12373
Jacobs
4026

Attention Mr Steve Nel

Dear Sir

Foam Asphalt Mix Design - Coedmore RAP JC 1484

We refer to the foam asphalt mix design conducted on a blend of 85% RAP ex Colas Coedmore and 15 % crusher dust ex Ridgeview Quarry.

Attached please find the foam asphalt mix design as well as the moisture density relationship of the mixture.

The repeated load testing was done using a Nottingham Asphalt Tester and the following test conditions:

Dynamic creep modulus

100 kPa, 40 °C, 30 pulses conditioning and then a further 3600 pulses at 0.5 Hz, square wave form.

Resilient modulus

120 ms rise time, 5μm horizontal deformation, 25 °C , assumed Poisson's ratio of 0,4.

We wish to thank you for your valued support and should you require any further information please feel free to contact us.

Yours faithfully

C.H.Loots
Manager

SOILS DESIGN LABORATORIES (NATAL)

MOISTURE/DENSITY RELATIONSHIP

Client : Bitutek Laboratory Job Card No.: 63424

Project : Order No.4/45 Sample No. : 7410

Date : 12-11-96

Field/Pit No.: Material Description : Rap + 15% CO

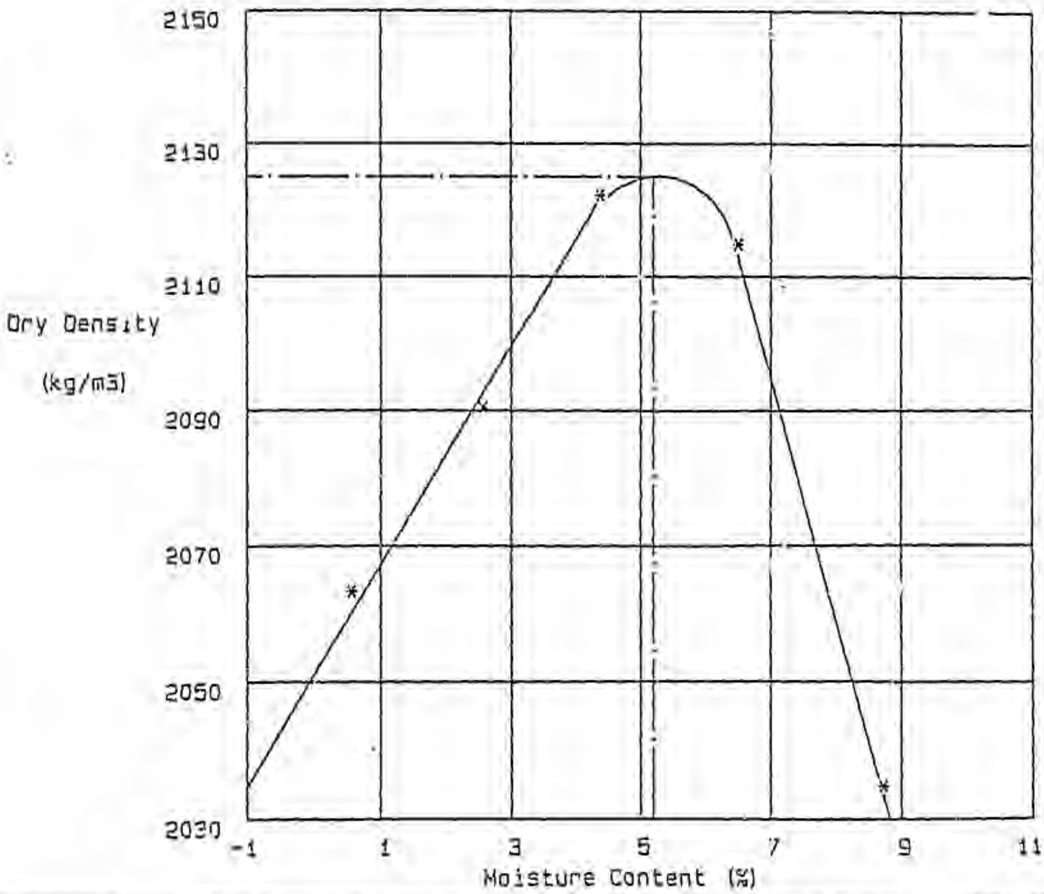
Position : 87068

Depth : Stabilising Agent : Natural

Moisture / Density Relationship

Nominal Moisture Content	(%)	0	2	4	6	8
Dry Density	(kg/m3)	2063	2090	2122	2115	2035
Moisture Content	(%)	0.6	2.6	4.4	6.5	8.7

MAXIMUM DRY DENSITY : 2125 kg/m3
OPTIMUM MOISTURE CONTENT : 5.2 %



BITUTEK LABORATORY (PTY)LTD

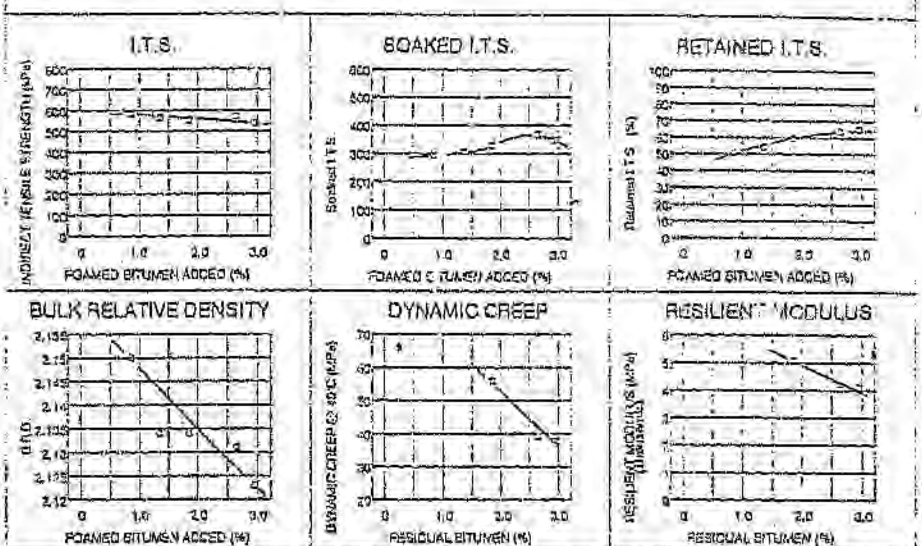
FOAM ASPHALT STABILISATION

CLIENT : Colas East (Pty) Ltd JC No : 1484

JOB : Coedmore RAP DATE : 22/11/95

AGGREGATE : RAP 85%, Crusher Dust 15% CODE :

BITUMEN : 150/200 EX SAPREF



NOMINAL BINDER ADDED	0.5%	1.0%	1.5%	2.0%	2.5%			
BITUMEN CONTENT RAP (%)			3.7					
BITUMEN CONTENT RAP + FOAM %	4.5	5.0	5.5	6.3	6.6			
BITUMEN CONTENT ADDED (%)	0.8	1.3	1.8	2.6	2.9			
MOISTURE CONTENT (%)	3.4	3.5	3.1	3.3	3.2			
BULK RELATIVE DENSITY	2.150	2.134	2.134	2.101	2.123			
SOAKED I.T.S. (kPa)	296	305	329	366	350			
I.T.S. (kPa)	583	564	581	573	538.0			
RETAINED I.T.S. (%)	50.8	54.1	59.3	63.9	65.1			
DYNAMIC CREEP MODULUS (MPa)			63.9	39.2	39.4			
RESILIENT MODULUS (MPa)			5090	4040	4113			
MOD AASHTO (kg/m³)				2125				
OMC – (MOD AASHTO) (%)				6.2				
OPTIMUM MOISTURE CONTENT (%)				3.9				

LABMAN (PTY) LTD

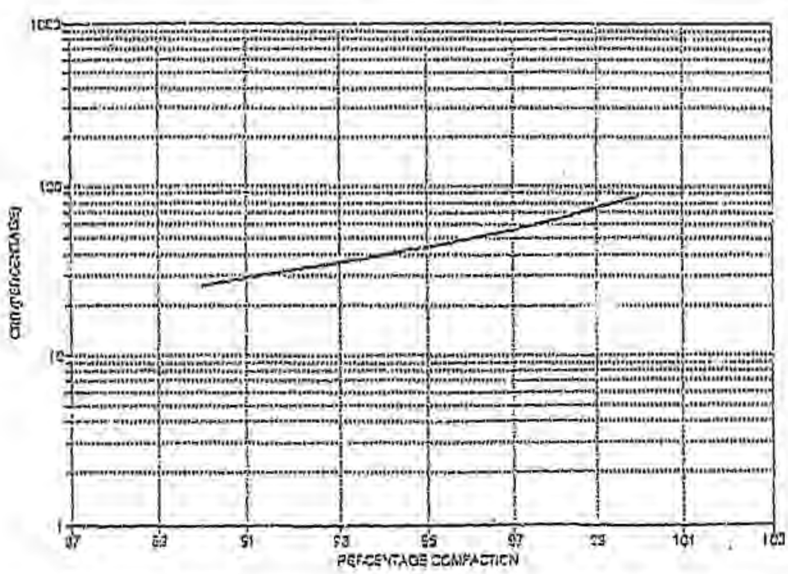
SOIL EXPERTS
P. O. Box 16698, PRETORIA NORTH 0116
TEL: (012) 546-0020

CBR RESULTS

DATE:	11/06/96
SITE:	DOORNKOP
CLIENT:	OPTIMUM
DETAILS:	FOAM BITUMEN STOCKPILE
LAYER:	PROPOSED SUBBASE
STABILISATION:	UNSTABILISSED/FOAM BITUMEN
SAMPLE No.:	K 211

CBR (CALIFORNIA BEARING RATIO)

	UNSTABILISED	STABILISED
MAXIMIMUM DRY DENSITY	2038	
OPTIMUM MOISTURE CONTENT	11.6	
COMPACTION MOISTURE CONTENT	12.1	
CBR AT 100% COMPACTION	87	
CBR AT 98% COMPACTION	64	
CBR AT 97% COMPACTION	56	
CBR AT 95% COMPACTION	44	
CBR AT 93% COMPACTION	36	
CBR AT 90% COMPACTION	26	
SWELL (MAXIMUM) (%)	0.31	



Received 9/06/97

LABMAN (PTY) LTD

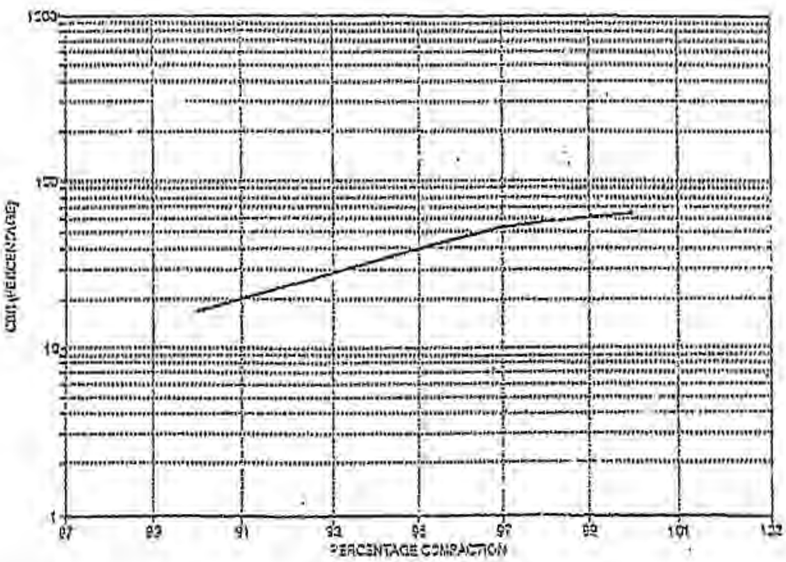
SOIL EXPERTS
P. O. Box 19698, PRETORIA NORTH 0116
TEL: (012) 545-0023

CBR RESULTS

DATE:	11/06/96
SITE:	DOORNKOP
CLIENT:	OPTIMUM
DETAILS:	FOAM BITUMEN STOCKPILE
LAYER:	PROPOSED SUBBASE
STABILISATION:	UNSTABILISSED/FOAM BITUMEN
SAMPLE No.:	K 204

CBR (CALIFORNIA BEARING RATIO)

	UNSTABILISED	STABILISED
MAXIMIMUM DRY DENSITY	2032	
OPTIMUM MOISTURE CONTENT	12.2	
COMPACTION MOISTURE CONTENT	12.0	
CBR AT 100% COMPACTION	65	
CBR AT 98% COMPACTION	57	
CBR AT 97% COMPACTION	54	
CBR AT 95% COMPACTION	40	
CBR AT 93% COMPACTION	28	
CBR AT 90% COMPACTION	17	
SWELL (MAXIMUM) (%)	0.79	



9/06/97

LABMAN (PTY) LTD

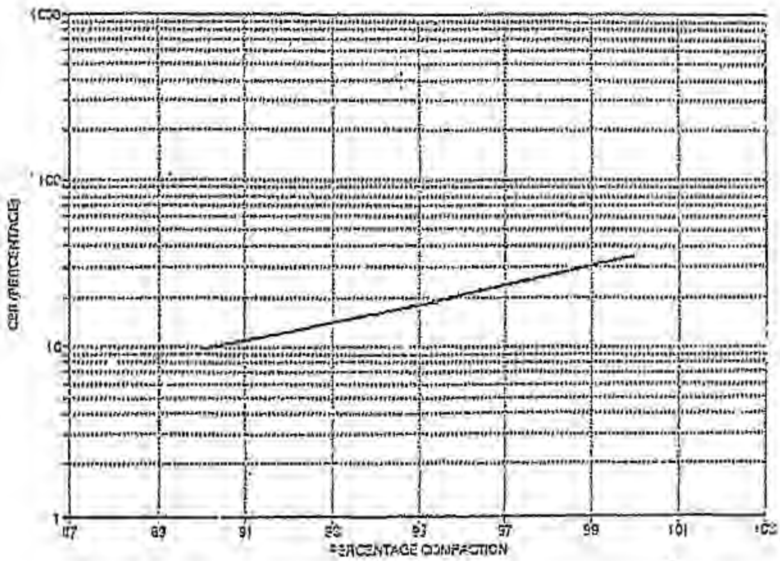
SOIL EXPERTS
P. O. Box 19695, PRETORIA NORTH 0116
TEL: (012) 546-0290

CBR RESULTS

DATE:	11/06/96
SITE:	DOORNKOP
CLIENT:	OPTIMUM
DETAILS:	FOAM BITUMEN STOCKPILE
LAYER:	PROPOSED SUBBASE
STABILISATION:	UNSTABILISSED/FOAM BITUMEN
SAMPLE No.:	K 203

CBR (CALIFORNIA BEARING RATIO)

	UNSTABILISED	STABILISED
MAXIMIMUM DRY DENSITY	2024	
OPTIMUM MOISTURE CONTENT	12.1	
COMPACTION MOISTURE CONTENT	11.8	
CBR AT 100% COMPACTION	35	
CBR AT 98% COMPACTION	26	
CBR AT 97% COMPACTION	23	
CBR AT 95% COMPACTION	18	
CBR AT 93% COMPACTION	14	
CBR AT 90% COMPACTION	10	
SWELL (MAXIMUM) (%)	0.49	



Received
9/06/9

BITUTEK LABORATORY (PTY) LTD

Registration Number 70/12/63/07

1996

08 January 1995

Bitufoam (Pty) Ltd
P.O.Box 12372
Jacobs
4026

Attention Mr Martin Koekemoer / Tony Lewis

Soweto - Foamed Red Chert (J.C.C.) JC 1057

We refer to the 3 samples of foamed chert ex Gauteng delivered to our laboratory on the 14 th of December 1995 for the determination of the moisture and binder contents as well as the dry and soaked stabilities in order to determine the retained stability . The samples were scalped at the 26,5 mm sieve before testing. The samples were dried to the given optimum moisture content of 8% before compaction. Sample 1 was cured for 1 day @ 60°C in a forced draft oven . The other samples were cured for 3 days.

The results are as follows:

Laboratory Number	B 5257	B 5258	B 5259	B5260
Field Number	1	2	3	4
Description	No Quartz	No Quartz	+ 37,5mm Quartz	+53,0 mm Quartz
Curing Period (Days)	1	3	3	4
Bulk Relative Density	2.040	2,036	2.048	2.043
Moisture Content (%)	10.5	9,6	9.2	8.4
M.C. at Compaction (%)	8,0	8.0	8.0	8.0
Binder Content (%)	4.6	4.0	4.4	4.4
Dry Stability (kN)	20.9	25.2	23.1	21.2
Soaked Stability (kN)	4.8	7.2	14.0	9.1
Retained Stability (%)	23.0	28.6	60.6	42.9

Received 9/06/97

BITUTEK LABORATORY (PTY) LTD

Registration Number 79/02692/07

Post-it Fax Pad 7551	Page: of
To:	From:
Co.	Co:
Dept.	Phone No.
Fax No.	Fax No.

23 November 1995

Bitufoam (Pty) Ltd
P.O.Box 12372
Jacobs
4026

JCC Foam JC 1020

We refer to the sample of foamed chert ex Johannesburg delivered to our laboratory on the 15th of November 1995 for the determination of the moisture and binder contents as well as the dry and soaked stabilities. Seven Briquettes were compacted and the balance not tested is available should further tests be required.

The results are as follows:

Laboratory Number		B5100
Field Number		
Bulk Relative Density		2.043
Moisture Content	(%)	6.7
Binder Content	(%)	4.4
Dry Stability	(kN)	17.3
Soaked Stability	(kN)	9.9
Retained Stability	(%)	57.2

We wish to thank you for your valued support and should you require any further information please feel free to contact us.

Yours faithfully

C.H.Loots
Manager

26 Westmead Road, Pinetown 3600 P O Box 15324 Westmead 3608 South Africa
Telephone: 031 - 700 4810 Fax: 031 - 700 3165
DIRECTORS: R M Dunbar P J Hechter A J N Lewis S J Emery* *Australian

Received 9/06

A.A. LOUDON & PARTNERS
CONSULTING ENGINEERS

3 St Mary's Road
Kloof, 3610
PO Box 543
Kloof, 3640

Telephone: 031-764 0152
Facsimile: 031-764 3143

18 October 1995

Our Ref 6000.03

Mr J Hattingh
Messrs Potgieter, Hattingh & Schultz
P O Box 2504
HONEYDEW
2040

FAX No. 011-792 8090

Dear Johan

FOAMED BITUMEN TREATMENT OF MATERIAL FROM DOORNKOP BORROW PIT, SOWETO

As discussed earlier today, we carried out a mix design on the material which you kindly supplied us from the Doornkop Borrow Pit.

As can be seen from the attached mix design (Job Card No. 910 dated 10/10/95) the Retained Stability tends to be very low. While the dry Marshall Stabilities are around 27 kN, the stability of the vacuum soaked specimens are low at approximately 4kN.

This is surprising as mixes previously carried out on material from this area last year, which were of an inferior quality (G6/G7), gave significantly better results (see attached design dated 20.8.94).

Unfortunately we do not have sufficient material to repeat the design, but as you mentioned in our discussion you would be able to supply us with another sample.

During the course of the mixing we will be carrying out tests to determine retained stability as part of our routine process control testing programme.

I have requested Bitutek to carry out Resilient Modulus and Dynamic Creep tests on spare briquettes left over from the mix design, at 3.5% and 4.0% bitumen contents.

At the time of writing, the results of the Dynamic Creep tests at 4.0% bitumen is available, the Creep modulus being 162.9 MPa. In view of this very high modulus, which indicates a high resistance to rutting, there would be benefit in using a 150/200 pen bitumen instead of the 80/100 pen used in the design. You may wish to discuss this with Graham Rutland.

As discussed I would be pleased to go through my paper on foamed bitumen with you on Tuesday 24 October, should you so wish.

Please do not hesitate to phone me should you have any queries.

Yours sincerely

Tony Lewis

BITUTEK LABORATORY (PTY)LTD

Recd 9/06/0

MIX DESIGN

JC No: 353

FOAM ASPHALT STABILISATION

DATE : 20/6/94

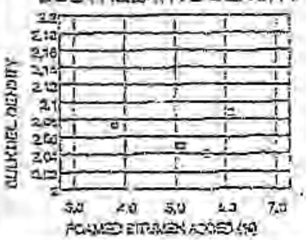
CONTRACTOR : SOTER AFRIQUE

CODE:

CLIENT : JOHANNESBURG CITY COUNCIL

AGGREGATE : CHERT

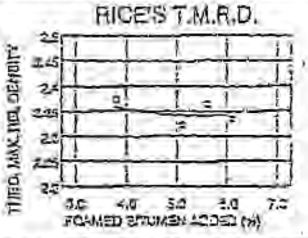
BULK RELATIVE DENSITY



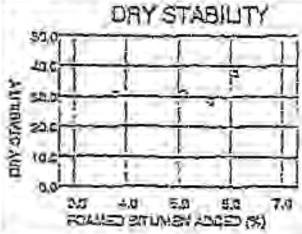
SOAKED STABILITY

SOAKED RESMOD

RICE'S T.M.R.D.

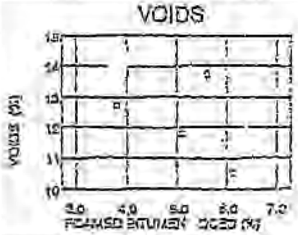


DRY STABILITY

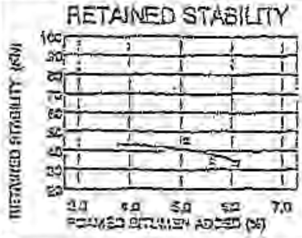


RESILIENT MODULUS

VOIDS



RETAINED STABILITY



RETAINED RESMOD

RESIDUAL BITUMEN (%)	3.6	5.1	5.6	6.1		SPEC
MOISTURE CONTENT (%)	6.2	7.3	7.6	6.7		
VOID CONTENT (%)	12.7	11.8	13.7	10.5		
BULK RELATIVE DENSITY	2.073	2.049	2.040	2.068		
THEORETICAL MAXIMUM RELATIVE DENSITY	2.375	2.323	2.365	2.333		
SOAKED STABILITY (KN)	12.9	13.9	9.3	12.3		
DRY STABILITY (KN)	30.5	31.1	26.7	37.4		
RETAINED STABILITY (%)	42.5	44.7	34.1	32.9		
RESILIENT MODULUS DRY (MPa)						
RESILIENT MODULUS SOAKED (MPa)						
RETAINED RESILIENT MODULUS (%)						
OPTIMUM MOISTURE CONTENT (%) (80% of MODAASHO)	4.8	4.8	4.8	4.8		

Received 9/04/97

BITUTEK LABORATORY (PTY)LTD

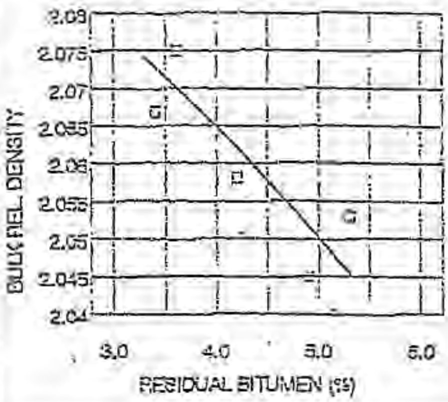
FOAM ASPHALT STABILISATION

CLIENT : Bitufoam (Pty) Ltd — JC No : 910

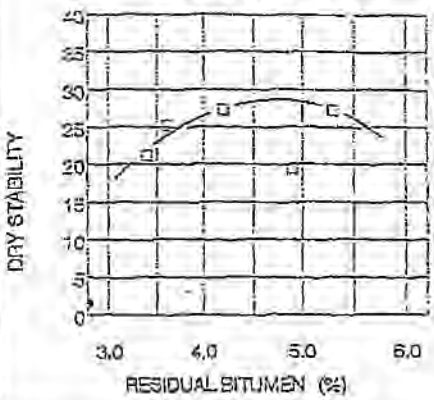
JOB : Trial Section JCC — DATE : 10/10/95

AGGREGATE : Weathered Chert — CODE :

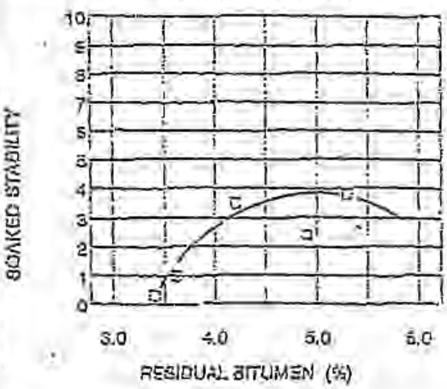
BULK RELATIVE DENSITY



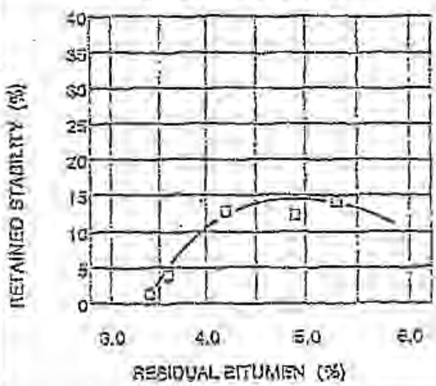
DRY STABILITY



SOAKED STABILITY



RETAINED STABILITY



MIX NUMBER	2.5%	3.0%	3.5%	4.0%	4.5%
BITUMEN CONTENT (%)	3.4	3.6	4.2	4.9	5.3
MOISTURE CONTENT (%)	5.5	6.0	5.7	6.0	6.6
BULK RELATIVE DENSITY	2.067	2.075	2.053	2.045	2.053
SOAKED STABILITY (KN)	0.3	1.0	3.5	2.4	3.8
DRY STABILITY (KN)	21.1	25.2	27.3	19.4	27.2
RETAINED STABILITY (%)	1.4	4.0	12.6	12.4	14.0

18 October 1995

Our Ref 8000.03

A.A. LOUDON & PARTNERS
CONSULTING ENGINEERS

2 St Mary's Road
Kloof 3610
PO Box 543
Kloof 3640

Telephone: 031-764 0153
Facsimile: 031-764 3143

Mr J Hattingh
Messrs Potgieter, Hattingh & Schultz
P O Box 2504
HONEYDEW
2040

FAX No. 011- 792 8090

Dear Johan

FOAMED BITUMEN TREATMENT OF MATERIAL FROM DOORNKOP BORROW PIT, SOWETO

As discussed earlier today, we carried out a mix design on the material which you kindly supplied us from the Doornkop Borrow Pit.

As can be seen from the attached mix design (Job Card No. 910 dated 10/10/95) the Retained Stability tends to be very low. While the dry Marshall Stabilities are around 27 kN, the stability of the vacuum soaked specimens are low at approximately 4kN.

This is surprising as mixes previously carried out on material from this area last year, which were of an inferior quality (G6/G7), gave significantly better results (see attached design dated 20.3.94).

Unfortunately we do not have sufficient material to repeat the design, but as you mentioned in our discussion you would be able to supply us with another sample.

During the course of the mixing we will be carrying out tests to determine retained stability as part of our routine process control testing programme.

I have requested Bitutek to carry out Resilient Modulus and Dynamic Creep tests on spare briquettes left over from the mix design, at 3.5% and 4.0% bitumen contents.

At the time of writing, the results of the Dynamic Creep tests at 4.0% bitumen is available, the Creep modulus being 152.9 MPa. In view of this very high modulus, which indicates a high resistance to rutting, there would be benefit in using a 150/200 pen bitumen instead of the 80/100 pen used in the design. You may wish to discuss this with Graham Rutland.

As discussed I would be pleased to go through my paper on foamed bitumen with you on Tuesday 24 October, should you so wish.

Please do not hesitate to phone me should you have any queries.

Yours sincerely

Tony Loudon

BITUTEK LABORATORY (PTY)LTD

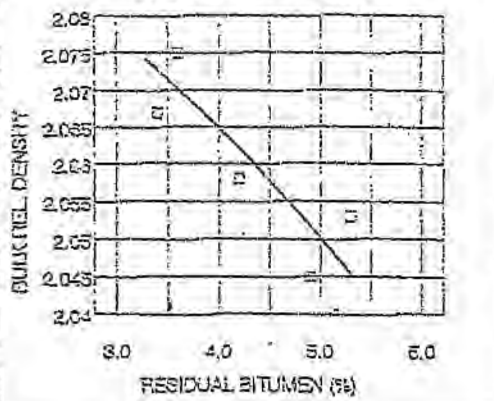
FOAM ASPHALT STABILISATION

CLIENT : Bitufoam (Pty) Ltd — JC No : 910

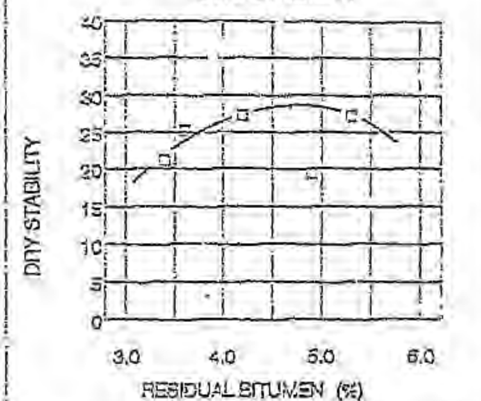
JOB : Trial Section JCC — DATE : 10/10/95

AGGREGATE : Weathered Chert — CODE :

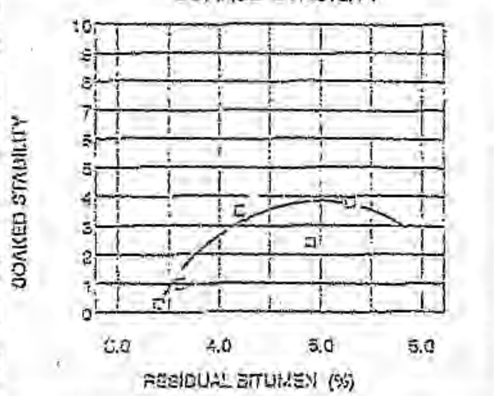
BULK RELATIVE DENSITY



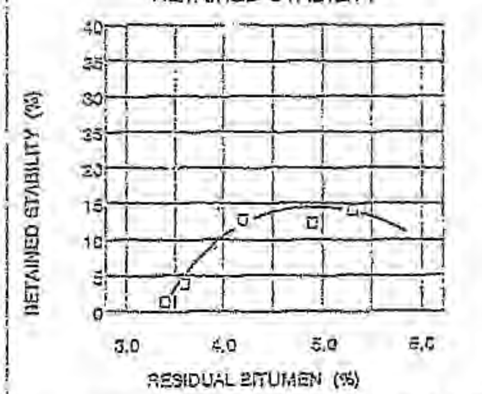
DRY STABILITY



SOAKED STABILITY



RETAINED STABILITY



MIX NUMBER	2.5%	3.0%	3.5%	4.0%	4.5%
BITUMEN CONTENT (%)	3,4	3,6	4,2	4,9	5,3
MOISTURE CONTENT (%)	5,5	5,0	5.7	6,0	6,6
BULK RELATIVE DENSITY	2.067	2.075	2,058	2,045	2,053
SOAKED STABILITY (KN)	0,3	1,0	3,5	2.4	3,6
DRY STABILITY (KN)	21.1	25,2	27,3	19.4	27,2
RETAINED STABILITY (%)	1,4	4.0	12,8	12.4	14.0

APPENDIX C:

Results for Duku Duku Sand and Coedmore RAP

BITUTEK LABORATORY (PTY) LTD

Registration Number 79/03693/07

11 June 1997

Brian T. Ghasi
University of Witwatersrand
West Campus Village
Flat D 12
2050

Attention Mr Brian T. Ghasi

Dear Sir

FOAMED ASPHALT STOCKPILE INVESTIGATION. JC 1726

We refer to the samples of Foamed Asphalt from the abovementioned project that was received during May 1997 for the determination of the Binder Content, Moisture Content and Indirect Tensile Strength (Dry and soaked), before and after the determination of the optimum moisture contents.

Attached please find "Foamed Asphalt Investigation" reports depicting the results.

Should you require any further information please feel free to contact us.

Yours faithfully

C.H. Loots
Manager

BITUTEK LABORATORY (PTY) LTD
FOAMED ASPHALT INVESTIGATION

CLIENT : Brian T. Ghasi
PROJECT : Foam Stockpile Investigation
ORDER NO :
ATTENTION : Mr Brian Ghasi

DATE : 09/06/1997
DATE REC. : MAY 1997
JC NO : 1726

LABORATORY NUMBER	DESCRIPTION	MOISTURE CONTENT	*BINDER CONTENT	BULK REL. DENSITY	DRY I.T.S.	SOAKED I.T.S.	RETAINED I.T.S.
JOHANNESBURG / SOWETO STOCKPILE							
BEFORE OPTIMUM MOISTURE CONTENT DETERMINATION							
B 9010	12 MONTHS – 1 m FROM TOP SURFACE – INSIDE	11.2	3.2	2.028	415	COLLAPSED	–
B 9011	12 MONTHS – 550 mm FROM THE TOP – UNDISTURBED	11.8	2.4	2.039	427	COLLAPSED	–
B 9012	12 MONTHS – 100 mm SURFACE – UNDISTURBED	6.1	2.9	1.860	159	COLLAPSED	–
B 9013	12 MONTHS – SURFACE – DISTURBED	6.0	3.2	1.847	82	COLLAPSED	–
B 9014	6 MONTHS STOCKPILE – 6 MONTHS IN BAGS	14.9	2.9	1.933	258	COLLAPSED	–
AFTER OPTIMUM MOISTURE CONTENT DETERMINATION							
B 9010	12 MONTHS – 1 m FROM TOP SURFACE – INSIDE	10.7	–	2.045	364	COLLAPSED	–
B 9011	12 MONTHS – 550 mm FROM THE TOP – UNDISTURBED	10.7	–	2.046	393	COLLAPSED	–
B 9012	12 MONTHS – 100 mm SURFACE – UNDISTURBED	10.7	–	2.033	339	COLLAPSED	–
B 9013	12 MONTHS – SURFACE – DISTURBED	10.7	–	2.010	405	COLLAPSED	–
B 9014	6 MONTHS STOCKPILE – 6 MONTHS IN BAGS	10.1	–	1.966	237	COLLAPSED	–

BITUTEK LABORATORY (PTY) LTD

FOAMED ASPHALT INVESTIGATION

CLIENT : Brian T. Ghasi
PROJECT : Foam Stockpile Investigation
ORDER NO :
ATTENTION : Mr Brian Ghasi

DATE : 09/06/1997
DATE REC. : MAY 1997
JC NO : 1726

LABORATORY NUMBER	DESCRIPTION	MOISTURE CONTENT	BINDER CONTENT	BULK REL. DENSITY	DRY I.T.S.	SOAKED I.T.S.	RETAINED I.T.S.
DURBAN / COEDMORE STOCKPILE							
BEFORE OPTIMUM MOISTURE CONTENT DETERMINATION							
B 9015	RM 1	2.9	6.6	2.037	479	385	80.4
B 9016	RM 4	3.5	6.5	2.058	567	364	64.2
B 9017	RM 5	4.9	7.1	2.045	566	465	82.2
B 9018	RM 7	3.4	7.8	2.084	470	408	86.8
B 9019	RTM 1	3.9	5.0	2.159	707	541	76.5
AFTER OPTIMUM MOISTURE CONTENT DETERMINATION							
B 9015	RM 1	6.0	–	2.061	471	420	89.2
B 9016	RM 4	6.0	–	2.066	562	441	78.5
B 9017	RM 5	6.0	–	2.081	573	505	88.1
B 9018	RM 7	6.0	–	2.167	561	409	72.9
B 9019	RTM 1	6.0	–	2.052	494	395	80.0

BITUTEK LABORATORY (PTY) LTD
FOAMED ASPHALT INVESTIGATION

CLIENT : Brian T. Ghasi
PROJECT : Foam Stockpile Investigation
ORDER NO :
ATTENTION : Mr Brian Ghasi

DATE : 09/06/1997
DATE REC. : MAY 1997
JC NO : 1726

LABORATORY NUMBER	DESCRIPTION	MOISTURE CONTENT	BINDER CONTENT	BULK REL DENSITY	DRY I.T.S.	SOAKED I.T.S.	RETAINED I.T.S.
DUKUDUKU STOCKPILE							
BEFORE OPTIMUM MOISTURE CONTENT DETERMINATION							
B 9021	DKM 1	13.7	5.0	1.765	267	189	70.8
AFTER OPTIMUM MOISTURE CONTENT DETERMINATION							
B 9021	DKM 1	10.5	–	1.787	250	186	74.4

SOILS DESIGN LABORATORIES (NATAL)
MOISTURE / DENSITY RELATIONSHIP

Client : Bitutek Laboratory
Project : Foam Stockpile - O/No.511

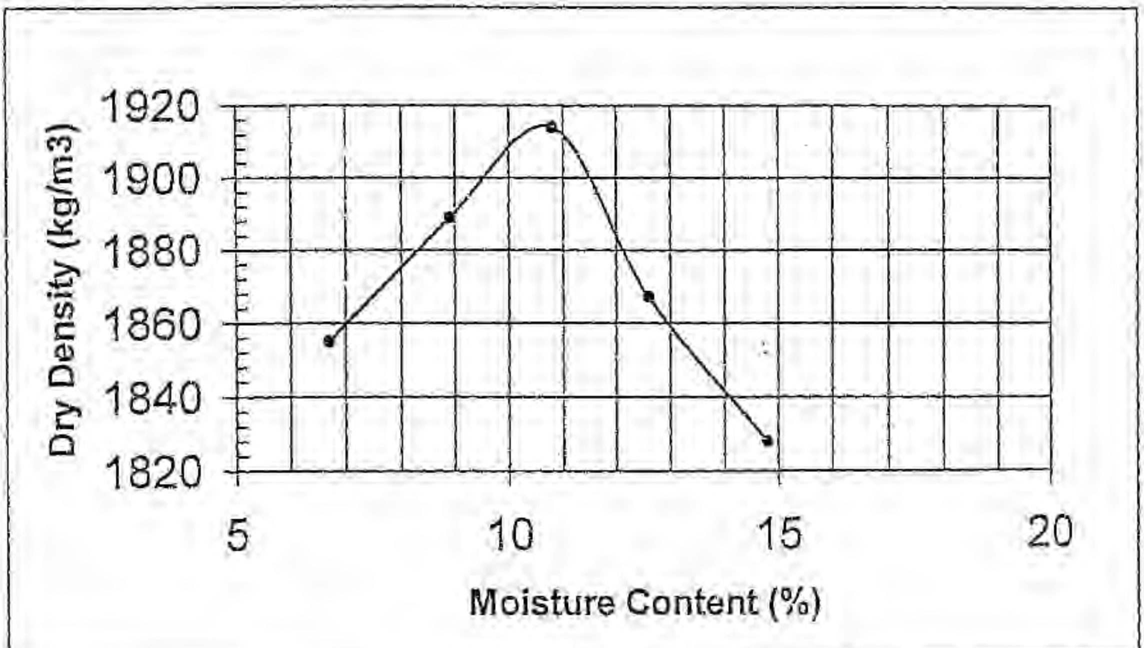
Job Card Number : 65474
Report Date : 28-05-97

Lab.No. : 8880
Field/Pit No. :
Position : B9010 JHB
Depth (mm) :

Material Description : Lt.R.Br.Clay + Gravel
Stabilising Agent : Natural

MOISTURE / DENSITY RELATIONSHIP

Nominal Moisture Content	(%)	2	4	6	8	10
Dry Density	(kg/m3)	1855	1889	1914	1867	1828
Moisture Content	(%)	6.7	8.9	10.8	12.6	14.8



Maximum Dry Density (kg/m3) : 1914

Optimum Moisture Content (%): 10.7

SOILS DESIGN LABORATORIES (NATAL)

MOISTURE / DENSITY RELATIONSHIP

Client : Bitutek Laboratory
Project : Foam Stockpile - O/No.511

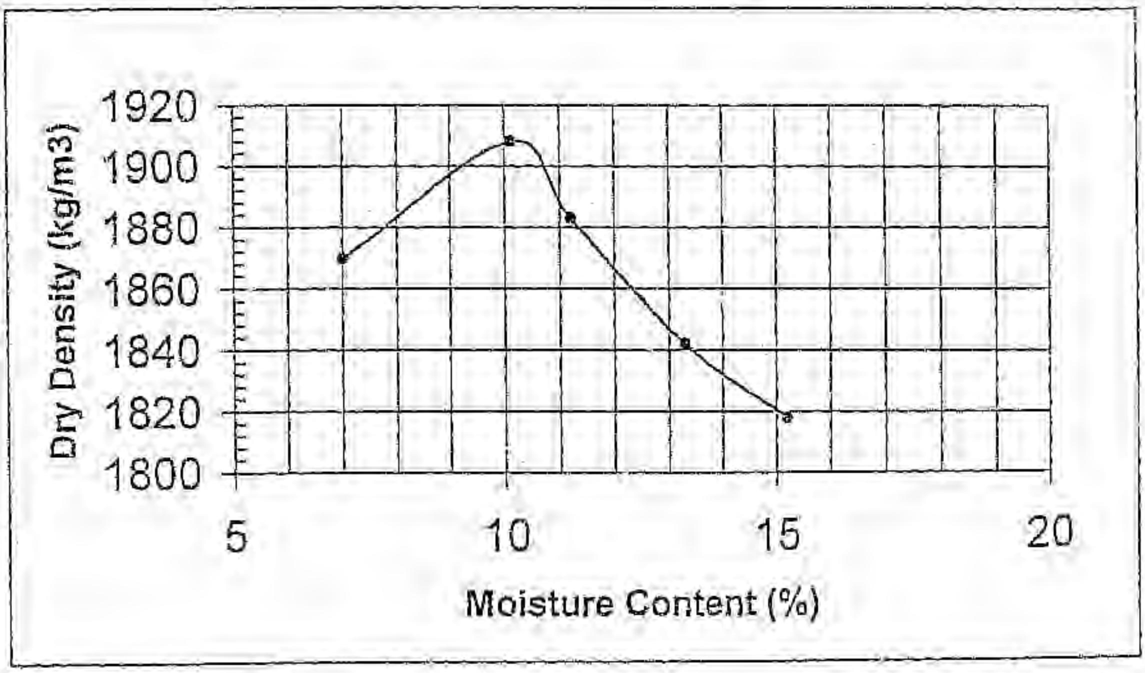
Job Card Number : 65474
Report Date : 28-05-97

Lab.No. : 8861
Field/Pit No. :
Position : B9014 JHB
Depth (mm) :

Material Description : Dk.R.Br.Clay
Stabilising Agent : Natural

MOISTURE / DENSITY RELATIONSHIP

Nominal Moisture Content	(%)	4	6	8	10	12
Dry Density	(kg/m3)	1870	1908	1883	1842	1818
Moisture Content	(%)	7.0	10.1	11.2	13.3	15.2



Maximum Dry Density (kg/m3) : 1914

Optimum Moisture Content (%): 10.1

SOILS DESIGN LABORATORIES (NATAL)

MOISTURE / DENSITY RELATIONSHIP

Client : Bitutek Laboratory
Project : Foam Stockpile - O/No.511

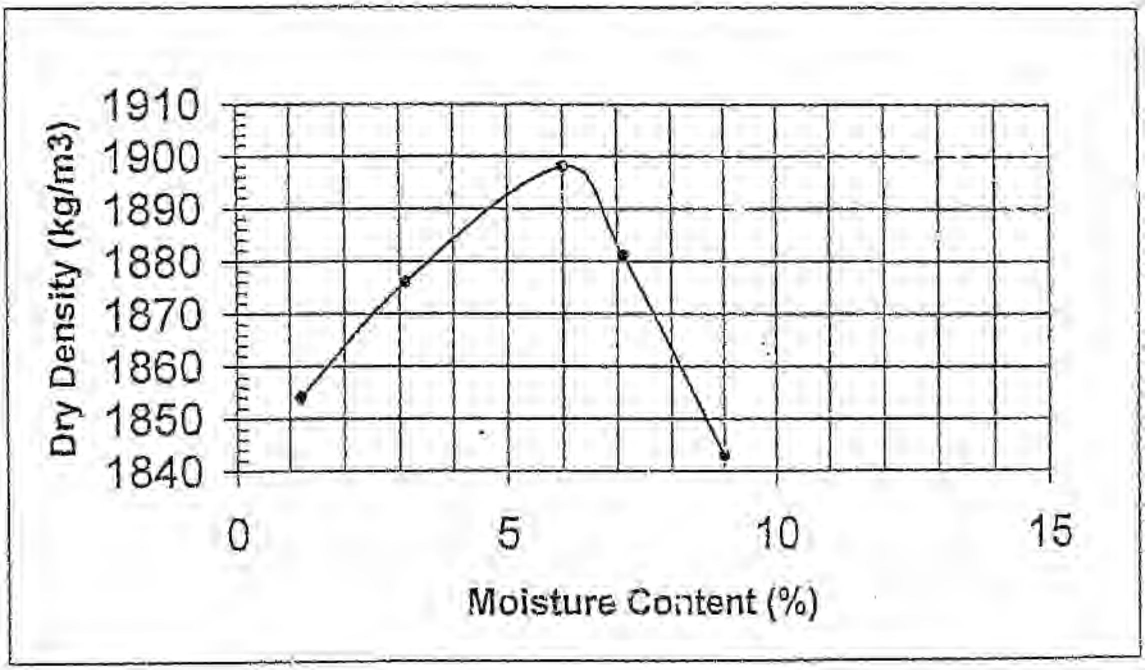
Job Card Number : 65474
Report Date : 28-05-97

Lab.No. : 8892
Field/Pit No. :
Position : B9015/18
Depth (mm) :

Material Description : Du.Bl.Dolerite Gravel + Premix
Stabilising Agent : Natural

MOISTURE / DENSITY RELATIONSHIP

Nominal Moisture Content	(%)	0	2	4	6	8
Dry Density	(kg/m3)	1854	1876	1898	1881	1843
Moisture Content	(%)	1.2	3.1	6.0	7.1	9.0



Maximum Dry Density (kg/m3) : 1902

Optimum Moisture Content (%): 6.0

SOILS DESIGN LABORATORIES (NATAL)

MOISTURE / DENSITY RELATIONSHIP

Client : Bitutek Laboratory
Project : Foam Stockpile - O/No.511

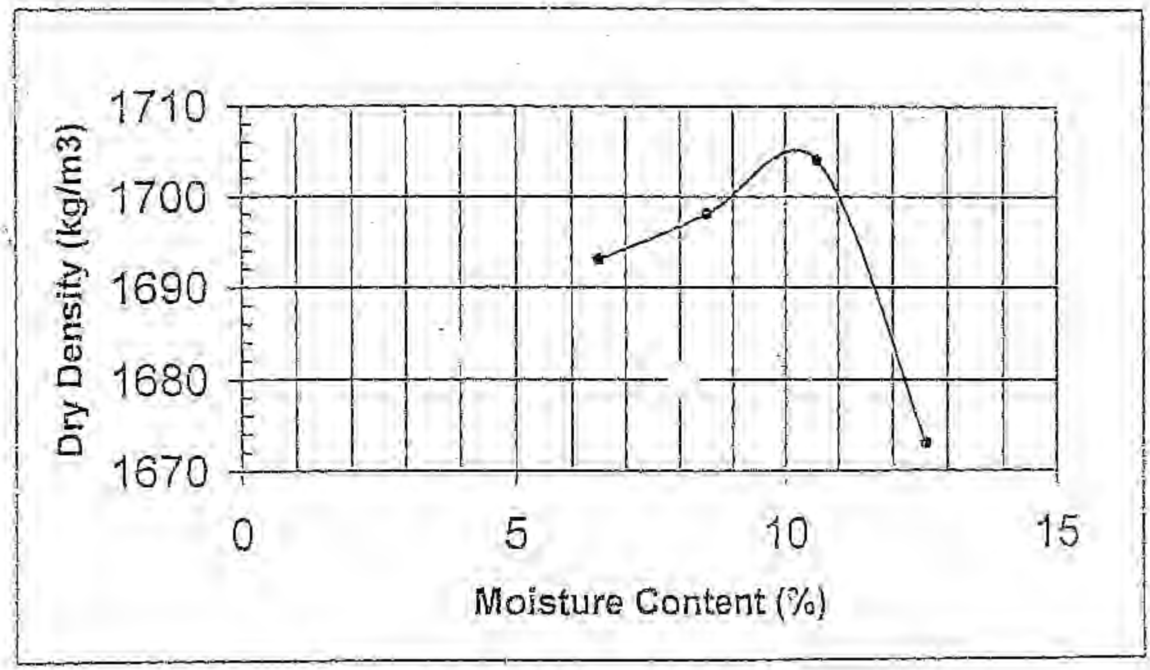
Job Card Number : 65474
Report Date : 28-05-97

Lab.No. : 8896
Field/Pit No. :
Position : B9021
Depth (mm) :

Material Description : Dk.Br.G.Sand
Stabilising Agent : Natural

MOISTURE / DENSITY RELATIONSHIP

Nominal Moisture Content	(%)	6	8	10	12
Dry Density	(kg/m3)	1693	1698	1704	1673
Moisture Content	(%)	6.5	8.[illegible]	10.6	12.6



Maximum Dry Density (kg/m3) : 1705

Optimum Moisture Content (%): 10.3

BITUTEK LABORATORY (PTY) LTD

Registration Number 79/02693/07

08 August 1997

Mr Brian T. Chasi
University of Witwatersrand
West Campus Village
Flat D 12
2050

Attention Mr Brian T. Chasi

Dear Sir

FOAMED ASPHALT STOCKPILE INVESTIGATION JC 1814

We refer to the three groups of samples of foamed asphalt for the abovementioned investigation that was received during July 1997 for testing.

The following was required:

Coedmore and Dukuduku:

Four and two samples were received respectively. The moisture contents were tested and adjusted to optimum moisture content as per design. Marshall briquettes were compacted at the normal compaction effort. The Retained I.T.S. values were determined.

Soweto:

Three samples were received. The moisture contents were tested and adjusted to the optimum moisture content as per design. Marshall briquettes were compacted at the normal compaction effort. The retained I.T.S. values were determined as well as the Marshall Stability and Flow at 25°C. A further addition of 1% of a 30% anionic stable grade emulsion was made to two of the samples and briquettes compacted for the determination of the retained I.T.S. This addition of diluted emulsion was over and above the optimum compaction moisture content.

Attached please find "Foamed Asphalt Investigation" reports depicting the results.

Should you require any further information please feel free to contact us.

Yours faithfully

C.H. Loots
Manager

25 Westmead Road, Pinetown 3600 P O Box 15324 Westmead 3608 South Africa
Telephone: 031 - 700 4510 Fax: 031 - 700 3165

BITUTEK LABORATORY (PTY) LTD

FOAMED ASPHALT INVESTIGATION

CLIENT : Mr Brian T. Chasi

PROJECT : Foam Stockpile Investigation

ORDER NO :

ATTENTION : Mr Brian Chasi

DATE : 08/08/1997

DATE REC. : July 1997

JC NO : 1814

LABORATORY NUMBER	DESCRIPTION	MOISTURE CONTENT BEFORE / AFTER	BINDER CONTENT (%)	BULK REL. DENSITY	DRY I.T.S (kPa)	SOAKED I.T.S. (kPa)	RETAINED I.T.S. (%)
		DURBAN / COEDMORE STOCKPILE					
		AFTER OPTIMUM MOISTURE CONTENT ADJUSTMENT					
B 9616	RJY 1	1.8 / 6.0	–	–	581	466	80.2
B 9617	RJY 4	1.6 / 6.0	–	–	572	411	71.9
B 9618	RJY 5	3.1 / 6.0	–	–	377	406	107.7
B 9619	RJY 7	3.4 / 6.0	–	–	516	397	76.9
		DUKUDUKU STOCKPILE					
		AFTER OPTIMUM MOISTURE CONTENT ADJUSTMENT					
B 9620	BAG NUMBER "1"	9.5 / 10.3	–	–	196	196	100.0
B 9621	BAG NUMBER "2"	9.3 / 10.3	–	–	233	218	93.6

BITUTEK LABORATORY (PTY) LTD
FOAMED ASPHALT INVESTIGATION

CLIENT : Mr Brian T. Chasi
PROJECT : Foam Stockpile Investigation
ORDER NO :

DATE : 08/08/1997
DATE REC. : JULY 1997
JC NO : 1814

LABORATORY NUMBER	DESCRIPTION	MOISTURE CONTENT BEFORE / AFTER (%)	BINDER CONTENT (%)	BULK REL. DENSITY	DRY I.T.S. (kPa)	SOAKED I.T.S. (kPa)	STABILITY AND FLOW (kN/mm)
	JOHANNESBURG / SOWETO STOCKPILE						
	AFTER OPTIMUM MOISTURE CONTENT ADJUSTMENT – BEFORE ADDITION OF EMULSION						
B 9613	SURFACE MATERIAL (100 mm)	6.8 / 10.7	–	–	345	COLLAPSED	29.1 / 2.4
B 9614	INSIDE – 500 mm FROM THE TOP	12.6 / 10.7	–	–	386	COLLAPSED	29.5 / 2.0
B 9615	6 MONTHS STOCKPILE – 6 MONTHS IN BAGS	15.2 / 10.7	–	–	432	COLLAPSED	26.5 / 2.1
	AFTER OPTIMUM MOISTURE CONTENT ADJUSTMENT – AFTER ADDITION OF 1 % EMULSION (30 %)						
B 9614	INSIDE – 500 mm FROM THE TOP	12.6 / 10.7	–	–	335	COLLAPSED	–
B 9615	6 MONTHS STOCKPILE – 6 MONTHS IN BAGS	15.2 / 10.7	–	–	319	COLLAPSED	–

BITUTEK LABORATORY (PTY) LTD
Registration Number 79/02693/07

16 September 1997

Mr Brian T. Chasi
University of Witwatersrand
West Campus Village
Flat D 12
2050

Attention Mr Brian T. Chasi

Dear Sir

FOAMED ASPHALT STOCKPILE INVESTIGATION JC 1862

We refer to the three groups of samples of foamed asphalt, for the above mentioned project, that was received during July 1997 for testing.

The following was required:

Coedmore :

Four samples were received. The moisture contents were tested and adjusted to the optimum moisture content as per design. Marshall briquettes were compacted at the normal compaction effort. The Retained I.T.S. values were determined.

Dukuduku :

Six samples were received. The moisture contents were tested and adjusted to the optimum moisture content as per design. Marshall briquettes were compacted at the normal compaction effort. The retained I.T.S. values were determined as well as the binder content of four of the samples.

Attached please find "Foamed Asphalt Investigation" reports depicting the results.

Should you require any further information please feel free to contact us.

Yours faithfully

C.H.Loots
Manager

25 Westmead Road, Pinetown 3600 P O Box 15324 Westmead 3608 South Africa

BITUTEK LABORATORY (PTY) LTD
FOAMED ASPHALT INVESTIGATION

CLIENT : Mr Brian T. Chasi
PROJECT : Foam Stockpile Investigation
ORDER NO :
ATTENTION : Mr Brian Chasi

DATE : 16/09/1997
DATE REC. : SEPTEMBER 1997
JC NO : 1862

LABORATORY NUMBER	DESCRIPTION	MOISTURE CONTENT BEFORE / AFTER	BINDER CONTENT (%)	BULK REL. DENSITY	DRY I.T.S. (kPa)	SOAKED I.T.S. (kPa)	RETAINED I.T.S. (%)
DURBAN / COEDMORE STOCKPILE							
AFTER OPTIMUM MOISTURE CONTENT ADJUSTMENT							
B 9768	RA 1	3.2 / 6.0	–	2.040	556	369	66.3
B 9769	RA 4	3.4 / 6.0	–	2.065	553	490	88.1
B 9770	RA 5	4.0 / 6.0	–	2.057	591	401	67.9
B 9771	RA 7	4.0 / 6.0	–	2.054	498	501	100.6
DUKUDUKU STOCKPILE							
AFTER OPTIMUM MOISTURE CONTENT ADJUSTMENT – RECEIVED 04/09/1997							
B 9772	DA 1	9.2 / 10.3	4.5	1.854	247	208	84.2
B 9773	DA 4	7.8 / 10.3	4.4	1.842	221	178	80.5
B 9774	DA 5	8.8 / 10.3	4.1	1.862	214	160	74.8
B 9775	DA 7	8.2 / 10.3	4.4	1.841	240	172	71.7
AFTER OPTIMUM MOISTURE CONTENT ADJUSTMENT – RECEIVED 11/09/1997							
B 9805	DA 1 – COVER STOCKPILE BOTTOM LEFT	10.1 / 10.3	–	1.840	257	185	72.0
B 9806	DA 4 – MIDDLE LEFT 1 kg	10.7 / 10.3	–	1.868	275	189	68.7

BITUTEK LABORATORY (PTY) LTD
Registration Number 79/02593/07

6 October 1997

Mr Brian T. Chasi
University of Witwatersrand
West Campus Village
Flat D 12
2050

Attention Mr Brian T. Ghasi

Dear Sir

FOAMED ASPHALT STOCKPILE INVESTIGATION JC 1915

We refer to the three groups of samples of foamed asphalt, for the above mentioned project, that was received during October 1997 for testing.

The following was required:

Coedmore :

Four samples were received. The moisture and binder contents were tested and adjusted to the optimum moisture content as per design. Marshall briquettes were compacted at the normal compaction effort. The Retained I.T.S. values were determined.

Dukuduku :

Eight samples were received. The moisture and binder contents were tested and adjusted to the optimum moisture content as per design. Marshall briquettes were compacted at the normal compaction effort. The retained I.T.S. values were determined :

Attached please find "Foamed Asphalt Investigation" reports depicting the results

Should you require any further information please feel free to contact us.

Yours faithfully

C.H.Loots P.P.

25 Westmead Road, Pinetown 3600 P O Box 15324 Westmead 3608 South Africa

BITUTEK LABORATORY (PTY) LTD

FOAMED ASPHALT INVESTIGATION

CLIENT : Mr Brian T. Chasi
PROJECT : Foam Stockpile Investigation
ATTENTION : Mr Brian Chasi

DATE :06/10/1997
DATE REC. : OCTOBER 1997
JC NO : 1915

LABORATORY NUMBER	DESCRIPTION	MOISTURE CONTENT BEFORE / AFTER	BINDER CONTENT (%)	BULK REL. DENSITY	DRY I. T. S. (kPa)	SOAKED I. T. S. (kPa)	RETAINED I. T. S. (%)
DURBAN / COEDMORE STOCKPILE							
AFTER OPTIMUM MOISTURE CONTENT ADJUSTMENT							
B 75	RAA 1	3.3 / 6.0	6.4	2.050	472	383	81.1
B 76	RAA 4	1.1 / 6.0	7.2	2.038	301	247	82.3
B 77	RAA 5	4.5 / 6.0	5.8	2.066	375	324	86.4
B 78	RAA 7	4.1 / 6.0	6.6	2.049	511	418	81.8
DUKUDUKU STOCKPILE							
AFTER OPTIMUM MOISTURE CONTENT ADJUSTMENT							
B 79	DAA 1	9.1 / 10.3	4.8	1.862	228	135	59.2
B 80	DAA 4	8.1 / 10.3	4.2	1.855	193	120	62.2
B 81	DAA 5	8.2 / 10.3	4.9	1.848	182	126	69.2
B 82	DAA 7	6.7 / 10.3	4.9	1.843	180	113	62.8
AFTER OPTIMUM MOISTURE CONTENT ADJUSTMENT							
B 83	CDAA 1	8.7 / 10.3	4.6	1.849	206	133	64.6
B 84	CDAA 4	7.3 / 10.3	4.7	1.839	240	189	78.7
B 85	CDAA 5	10.0 / 10.3	4.2	1.858	237	176	74.3
B 86	CDAA 7	7.1 / 10.3	3.7	1.856	179	132	73.7

APPENDIX D

Analysis of Interior and Exterior Properties of Stockpile

INTERIOR AND EXTERIOR PROPERTIES OF STOCKPILE

APPENDICE D.1

Material : FOAM STABILISED SAND

Bulk Relative Densities(covered)

Month	Avg External Results (Positions 1,4 and 7)	Internal Results (Position 5)
0	1.787	1.787
3	1.846	1.862
4	1.848	1.856

t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	1.827	1.835
Variance	0.001201	0.001737
Observations	3	3
Pearson Correlation	0.994914	
Hypothesized Mean D	0	
df	2	
t Stat	-1.73205	
P(T<=t) one-tail	0.112702	
t Critical one-tail	2.919987	
P(T<=t) two-tail	0.225403	
t Critical two-tail	4.302656	

Dry ITS (Covered)

Month	Avg External Results	Internal Results
0	250	250
2	214.5	214.5
3	236	214
4	208.3	237

t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	227.2	228.875
Variance	371.9266667	313.3958
Observatio	4	4
Pearson Co	0.37076716	
Hypothesiz	0	
df	3	
t Stat	-0.161147888	
P(T<=t) one	0.441108841	
t Critical or	2.353363016	
P(T<=t) two	0.882217682	
t Critical tw	3.182449291	

APPENDICE D.2

Soaked ITS (Covered)

Month	Avg External Results	Internal Results
0	189	189
2	207	207
3	186	160
4	151.3	176

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	183.325	183
Variance	541.8225	396.6667
Observations	4	4
Pearson Correlation	0.549974	
Hypothesized Mean D	0	
df	3	
t Stat	0.031399	
P(T<=t) one-tail	0.488462	
t Critical one-tail	2.353363	
P(T<=t) two-tail	0.976924	
t Critical two-tail	3.182449	

Retained ITS (Covered)

Month	Avg External Results	Internal Results
0	74.5	74.4
2	96.5	96.5
3	78.8	74.8
4	72.4	74.3

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	80.55	80
Variance	120.1633333	121.0467
Observatio	4	4
Pearson C	0.974565356	
Hypothesiz	0	
df	3	
t Stat	0.444044421	
P(T<=t) on	0.34354351	
t Critical or	2.353363016	
P(T<=t) tw	0.687087021	
t Critical tw	3.182449291	

APPENDIX E

Analysis on Effect of Covering Stockpile After Four Months

EFFECT OF COVERING THE STOCKPILE AFTER FOUR MONTHS

APPENDICE E.1

MATERIAL : FOAM STABILISED SAND

PARAMETER INVESTIGATED: Bulk Relative Density

Uncovered Results :	1.862	1.855	1.843	1.848
Covered Results :	1.849	1.839	1.856	1.856

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	1.852	1.85
Variance	6.87E-05	6.47E-05
Observations	4	4
Pearson Correlation	-0.60527	
Hypothesized Mean Difference	0	
df	3	
t Stat	0.273434	
P(T<=t) one-tail	0.401132	
t Critical one-tail	2.353363	
P(T<=t) two-tail	0.802263	
t Critical two-tail	3.182449	

PARAMETER INVESTIGATED: Dry ITS

Uncovered	228	193	180	182
Covered	206	240	179	237

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	195.75	215.5
Variance	494.916667	828.3333
Observations	4	4
Pearson Correlation	-0.04919738	
Hypothesized Mean I	0	
df	3	
t Stat	-1.06090456	
P(T<=t) one-tail	0.18328858	
t Critical one-tail	2.35336302	
P(T<=t) two-tail	0.36657717	
t Critical two-tail	3.18244929	

APPENDICE E.2

PARAMETER INVESTIGATED: Soaked ITS

Uncovered Results :	135	120	113	126
Covered Results :	133	189	132	176

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	123.5	157.5
Variance	87	861.6667
Observations	4	4
Pearson Correlation	-0.09496	
Hypothesized Mean Difference	0	
df	3	
t Stat	-2.14963	
P(T<=t) one-tail	0.060375	
t Critical one-tail	2.353363	
P(T<=t) two-tail	0.12075	
t Critical two-tail	3.182449	

PARAMETER INVESTIGATED: Retained ITS

Uncovered Results :	59.2	62.2	62.8	69.2
Covered Results :	64.6	78.8	73.7	74.3

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	63.35	72.85
Variance	17.69	35.43
Observations	4	4
Pearson Correlation	0.47147121	
Hypothesized Mean I	0	
df	3	
t Stat	-3.49739327	
P(T<=t) one-tail	0.01977764	
t Critical one-tail	2.35336302	
P(T<=t) two-tail	0.03955528	
t Critical two-tail	3.18244929	

APPENDIX F

Analysis on Interior and Exterior Properties of Stockpile

INTERIOR AND EXTERIOR PROPERTIES OF STOCKPILE

APPENDICE F.1

MATERIAL INVESTIGATED: FOAM STABILISED RAP

Bulk Ralative Density

Month	Avg External Results	Internal
2	2.098	2.081
5	2.053	2.057
6	2.046	2.066

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	2.065667	2.068
Variance	0.000796	0.000147
Observations	3	3
Pearson Correlation	0.875368	
Hypothesized Mean Difference	0	
df	2	
t Stat	-0.21779	
P(T<=t) one-tail	0.423895	
t Critical one-tail	2.919987	
P(T<=t) two-tail	0.84779	
t Critical two-tail	4.302656	

Dry ITS

Month	Avg External Results	Internal
2	531.3	573
4	556.3	377
5	536.7	591
6	428	375

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	513.075	479
Variance	3332.149	14200
Observations	4	4
Pearson Correlation	0.426[illegible]4	
Hypothesized Mean Difference	0	
df	3	
t Stat	0.630942	
P(T<=t) one-tail	0.286435	
t Critical one-tail	2.353363	
P(T<=t) two-tail	0.57287	
t Critical two-tail	3.182449	

APPENDICE F.2

Soaked ITS

Month	Avg External Results	Internal
2	423.3	505
4	424.7	406
5	453.33	401
6	349.3	324

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	412.6575	409
Variance	1975.57	5504.667
Observations	4	4
Pearson Correlation	0.611088	
Hypothesized Mean Difference	0	
df	3	
t Stat	0.124541	
P(T<=t) one-tail	0.454382	
t Critical one-tail	2.353363	
P(T<=t) two-tail	0.908763	
t Critical two-tail	3.182449	

Retained ITS

Month	Avg External Results	Internal
2	80.2	88.1
4	76.3	107.7
5	85	67.9
6	81.68	86.4

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	80.795	87.525
Variance	13.0081	264.5892
Observations	4	4
Pearson Correlation	-0.99174	
Hypothesized Mean Difference	0	
df	3	
t Stat	-0.67814	
P(T<=t) one-tail	0.273153	
t Critical one-tail	2.353363	
P(T<=t) two-tail	0.546306	
t Critical two-tail	3.182449	

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