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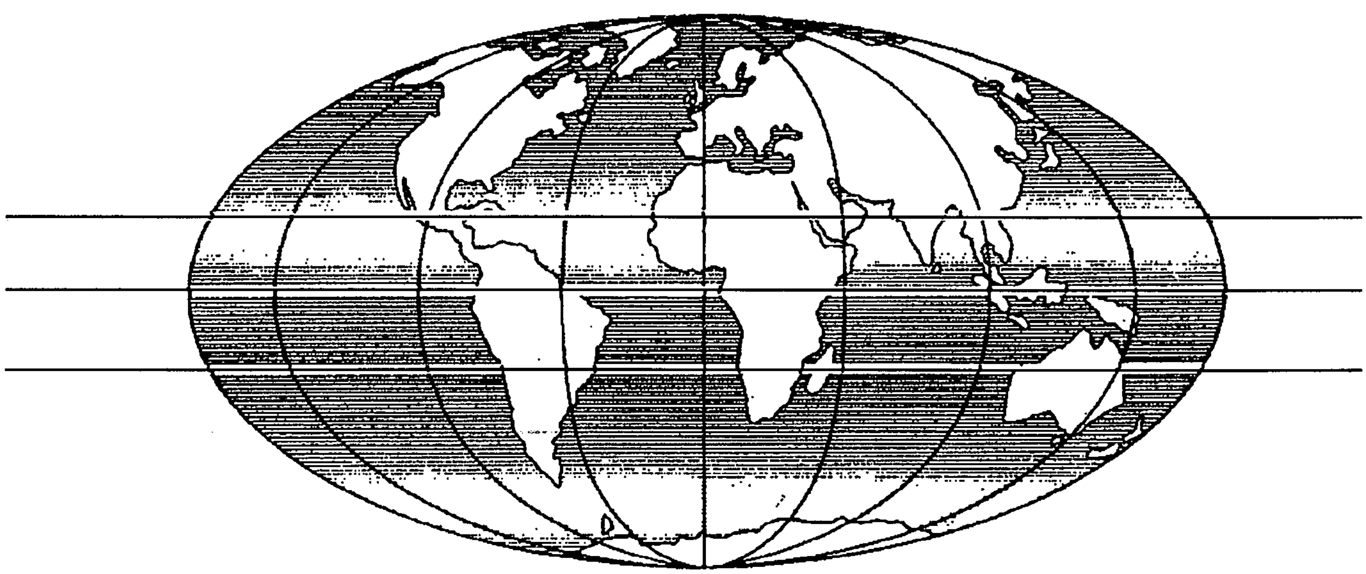

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A STRATEGY FOR ASSESSING MARGINAL QUALITY MATERIALS FOR USE IN BITUMINOUS ROADS IN THE TROPICS

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ABSTRACT

This paper describes studies performed by TRRL into the use of marginal quality materials for road pavement construction in the tropics. In the studies a strategy involving four main stages was followed. These included; mapping the location and distribution of materials, determining their properties in the field and in the laboratory, assessing their performance in road construction and under traffic and preparing guidelines for their use.

The studies were initiated to examine the use of locally abundant natural gravels and weathered rocks as alternatives to conventional materials in areas where the latter are unavailable or too expensive. Examples of studies of volcanic-derived gravels in Ethiopia and calcareous gravels in Botswana are used to illustrate the implementation of the strategy in practice.

It was shown that satisfactory performance of such marginal quality materials is likely to be very sensitive to the local climatic environment as well as; pavement drainage, method of construction, design traffic level and maintenance input. In determining the use of tropical materials additional identification tests are required to select suitable materials and to reject unsound ones. Various tests of a high or low cost are available to do this.

The results of the studies have shown that much wider use can be made of marginal materials than was previously suspected. This has enabled specifications to be drawn up in which their engineering properties and in some instances their mineralogical composition was taken into account.

It is suggested that the strategy described could be profitably used to conduct further studies of other tropical materials of widespread occurrence including, for example, laterites and soft, sedimentary deposits. Provided they were properly designed, built and monitored such studies could be undertaken by regional materials laboratories under the supervision of an experienced engineer. The full-scale trials of selected materials could be built as part of on-going construction projects. This will enable specifications to be developed and more confident, wider use to be made of local materials with resulting cost savings.

1. INTRODUCTION

In the planning and construction of roads in under-developed regions in the tropics sometimes conventional roadstone is unavailable in sufficient quantity or may be too expensive. As an alternative, natural gravels and weathered rocks are often abundant, and they can be exploited cheaply because they are relatively easy to win and haul distances are often minimal. However, such materials are commonly believed to be inadequate for road construction because of their softness and liability to degrade in use, and because of their often variable nature. The normal practice is to limit the use of 'marginal' materials to the best available, ie. those which most closely approach conventional pavement materials in terms of their hardness, grading and plasticity. Laterites and calcretes are well known examples of tropical "as dug" construction materials for which empirically derived selection criteria exist for their use in lightly-trafficked rural roads (1) (2). However,the success of such roads can often be attributed as much to dry climate and low traffic levels as to the high quality of material used. It has been found that by matching the design traffic levels to available materials, much 'poorer' quality materials can be adequate, while considerable savings can be made in construction cost by ease of extraction, employment of local labour and transport, and by the use of low technology production methods. The saving in construction cost can be large enough to make the difference between a road being economically justifiable and not.

With increased central planning and donor funding for road projects, greater emphasis is placed on economical and technical justification; no longer an ad-hoc process road planning increasingly follows a series of deliberate steps. It therefore provides the opportunity for economic use of marginal materials. However, in establishing that marginal materials can be used as successfully as conventional materials it is important that confidence in their identification, selection and method of use is developed. This requires an understanding of their behaviour in roads under tropical conditions and can only be obtained by a careful examination of their performance under traffic.

Over the past few years, the Overseas Unit of TRRL has conducted research in a number of tropical countries to find out how local materials of marginal quality can be satisfactorily evaluated in full-scale trials. The studies, which have been performed jointly with overseas government organisations, have examined a wide range of hitherto neglected tropical materials including weathered basalts in Ethiopia and Botswana, volcanic cinders, agglomerates and tuffs in Ethiopia, marly limestones in Belize and Jamaica, and calcretes in Botswana. The studies were carried out in a number of logical stages which correspond to the steps in a conventional road planning and construction process.

This paper describes the strategy which was adopted and gives details of its implementation in two of the studies, the results obtained and their application in practice. In the studies a strategy involving four main stages was followed. They were:

(i) mapping the location and distribution of materials. The location of material deposits, especially of the best sources, is generally unknown.

(ii) determining their engineering properties in the field and in the laboratory,

(iii) assessing their performance in road construction and under traffic

(iv) preparing guidelines and specifications for their use.

Details of the studies and the background to them are given below.

2. BACKGROUND TO THE USE OF MARGINAL MATERIALS

In many areas of the tropics, materials which satisfy the normal requirements for untreated road pavement materials are not always plentiful. When shortages exist the cost of production can be high and alternative solutions may be more feasible. The alternatives include the possibility of improving the local materials by the addition of a stabilising agent or the use of these materials in their natural state. The former solution has been used successfully in the tropics for many years (3) but the additional cost of providing the stabilising agent and the processing of the material has to be met. The greatest potential for savings can be achieved by making use of untreated local materials. This latter solution may at first seem unusual since the use of "local" materials is often taken to imply materials of an inferior quality. To some extent this is true, but only in so much that they may fail to meet the requirements of the particular specifications by which their quality is assessed. This is because the specifications have been derived for standards intended for roads built to meet higher traffic levels or have been adopted from those used in the industrialised countries and temperate climates of Europe and North America with little or no modification. However, in many areas of the tropics a large proportion of the countries are not fully developed and the traffic levels are relatively low (less than 300vpd). In the design of these roads, therefore, costs are very important and a limit on the amount of funds for construction often exists. Workable solutions which can reduce costs are therefore preferred and this can be brought about by developing appropriate design and material standards and construction practises locally. These would take account of the local availability of alternative materials.

Experience in using existing specifications overseas has in many cases shown their limitations. They are often unable to reject unsuitable materials and often unable to identify satisfactory materials. The former case is obviously the more alarming although, in both cases, it points to the lack of sufficient appreciation of the reasons behind material behaviour. The consequences are that either financial penalties will be incurred which were not anticipated or that potential savings will be lost.

The common reasons for excluding naturally occurring materials are that they may not satisfy the combined requirements of grading, plasticity, particle hardness and strength demanded by a specification (eg TRRL Road Note 31 (4)). However, satisfactory performance has been obtained from many materials which do not satisfy the requirements. Similarly, there are well known examples of failures being attributed to particular materials and their deficiences. The types of material which have been known to perform satisfactory in service, and which generally lie outside the requirements include such commonly occurring materials as laterites (1) and lateritic soils (5) and a wide range of materials formed through the accumulation of calcium carbonate. Common calcareous materials include corals, marly limestones and calcretes (2) (6). The reason given for the "better-than-average" performance is their reported self-cementing properties which is a result of both their physical and chemical composition. These are often reflected in improvements in their strength at in situ conditions. It is therefore suggested that provided they remain well-drained and covered by an impermeable bituminous seal they will give good service. By their nature however, they can be variable in situ and greater care is often required in using them.

Materials which often fail to perform satisfacorily and which often pass the selection stage include those of basic igneous origin. Although they appear to have the characteristics of competent rock or hard granualr material they may be decomposed to different degrees. The composition and origin of these rock types make them vunerable to chemical weathering through natural processes and this can lead to the alteration of certain rock minerals which they contain to to clay materials. In the combined presence of water and the action of vehicle loads the materials may degrade to a condition in which they would be unable to support traffic. Recent studies have shown that standard aggregate tests do not readily identify the problems associated with these materials (7) (8).

The objective of the studies described in this paper is therefore to understand more clearly the mechanisms responsible for material behaviour so that improvements can be made to selection procedures and appropriate tests developed that will lead to more predictable results being obtained. The stages involved include the location and identification of alternative materials, testing, processing, handling and road performance.

3. STAGES IN THE STUDIES

In planning the studies it was recognised that they should be undertaken in a number of logical stages which can be identified within the road planning process and in its implementation. They should also provide information for improving the procedures and specifications for future projects. It was also recognised that an important aspect of work in developing countries is the element of choice, particularly in relation to alternative materials and work methods. The objective should be to maximise the use of both the local materials resources and the available construction resources. The stages of a project which are commonly recognised include feasibility, design and implementation. In general, as a project proceeds an increasing amount of detail is required. However, for materials, alternatives are usually identified at an early stage, choices are then confirmed and finally acceptance of one or a number is made. This means that the early stages are often the most important therefore the planning and conduct of them needs to be done very thoroughly.

A further stage in the process which does not often concern the project engineer is the setting of design and investigation procedures and the derivation of a specification. In fact, in the long term, this stage is the most important since it forms the basis of acceptable procedure and practise. It can be recognised as a post-evaluation of the project and the specifications used. It involves the monitoring of road performance and can lead to new designs being formulated and accepted into everyday practise. Provided the evaluation is done using quantitive techniques the ability to compare the range of options using modern cost models will be available eg. the TRRL Road Investment Model RTIM2 (9).

The studies of marginal materials performed by the Overseas Unit have taken account of the above in their design and execution. As a result, the objectives and tasks involved in each of the different stages were clearly defined and are described below. During each stage it was important to consider the options available which could lead to improvements in existing methods and procedures and to examine new ones.

3.1. Location and distribution of materials.

The objective of this stage is to establish the general distribution and availability of the types of materials suitable for use in road construction. The tasks to be performed divide into desk and field studies.

3.1.1 The desk study. This involves the review of all materials related information and can be obtained from a number of sources. These include public and international libraries, government departments, engineering consultants and contractors, research organisations and universities. The basic information may be in the following forms:

Engineering reports

eg. feasibility studies, materials and design reports, construction reports, etc.

Scientific publications and journals

Maps (and accompanying bulletins)

eg. of geology, soils, topography, vegetation, hydrology, land use and climate.

Aerial photography

Satellite imagery

The data obtained from these sources can be combined to give an overall impression of the terrain and what it contains. If little information is available then a greater amount of field work would be required. The desk study therefore has an extremely important role in focusing and directing the fieldwork.

The developments which have been of greatest value to engineers in recent years has been the combined application of remote sensing techniques (10) and terrain evaluation (11) in the analysis of landforms and the interpretation of the relationships between these and their engineering characteristics. The existence of any such relationships can assist in the compilation of a geotechnical map for highway engineering purposes.

3.1.2 The field survey. This is intended to confirm or verify the results of the desk study and if necessay to locate and sample any new deposits required. The amount of work to be done depends on the quantity of the existing information and the success of the judgements made. The tasks to be done should include the following.

(i) Visit existing materials sources, examine the known information and obtain samples for check testing.

(ii) Locate new deposits or extend existing ones.

(iii) Conduct an exploratory pitting and sampling programme. At this stage perform simple field tests to assess the quality of the material, determine the approximate extent of the deposit and the quantity of suitable material.

(iv) On the basis of the results of (ii) and (iii) conduct an extensive pitting and sampling programme.

(v) Describe the engineering characteristics of the in situ material including thickness of overburden, workability and the thickness of the exploitable layer.

(vi) Record all the information in a data retrieval system.

As a result of the survey a preliminary map of materials resources can be drawn up. The inclusion of a limited amount of quantative testing at this stage and the recording of the results reduces wasteful sampling and testing and allows resources to be concentrated.

3.2 Laboratory testing and evaluation.

The objective of this stage is to determine the properties of the material in standard tests for selection purposes. In certain cases, additional tests may be required which have been found to be important in the classification of specific material types. Standard procedures exist in most countries (eg. BSI or ASTM) although slight variations may occur. In the initial assessment of materials, soil classification tests are usually performed. This involves the determination of the plasticity characteristics of the soil fines and the particle size distribution of the whole sample and enables the soil to be classified in relation to a recognised system eg. the British Soils Classification System (12). The value of such a system is that the variability within similar soils or broad differences can be identified as part of an initial screening stage. However, for road pavement materials further tests, including the strength of compacted samples etc, are required and, for marginal quality materials in the tropics, additional tests used in their identification and to determine their composition may be required.

The tests which are applied to pavement materials and which may be performed are listed below. They are divided into engineering and mineralogical tests. The mineralogical tests are less commonly performed.

Engineering tests:

(i) Particle size distribution

(ii) Soil plasticity

(iii) Particle hardness

(iv) Bearing or shear strength

(v) Compaction characteristics

Mineralogical tests:

(i) Chemical composition

(ii) Clay mineralology

(iii) Petrographic analysis

(iv) Deleterious mineral content

eg. soluble salts, organic content etc.

In addition to the above tests, special tests may be performed or test programmes undertaken which have been found suitable in further classifying the material. They have often been derived for use with specific material and therefore need to be used with discretion. Some of the tests included in this group are listed below.

Special tests:

(i) Weathering and durability tests
eg. Sodium and magnesium sulphate soundness tests, the slake durability test and the Texas ball mill test.

(ii) Cycled CBR tests
eg. wetting and drying.

(iii) Repeated compaction

(iv) Various tests based on mineralology are used to identify specific materials including calcium carbonate content (calcretes), sesquioxide ratio (laterites), secondary mineral count and dye absorption (weathered basalts).

3.3 Construction.

The suitability of materials for use depends on a number of factors. Firstly, they should be capable of consistently satisfying the requirements of the specification. Secondly, the methods of production and construction should take into account their in situ characteristics and behaviour during construction. The characteristics of marginal materials which influence the construction stage include the variability in the thickness of the selected layer and the under and overlying materials and the engineering properties of these layers. The particular aspects which concern the engineer include the following:

(i) stockpiling practise and processing of materials,

(ii) choice and availability of compaction plant and compaction methods,

(iii) surfacing requirements.

At this stage supervision and quality control become most important in order to achieve the specification. The design of the surfacing is also important since it provides the protection to the upper pavement. With this in mind, the origin of the surfacing design method and in particular its application to the substrate to be used should be considered. These factors are recognised as having a greater influence on natural materials. Furthermore, control methods though quantitative may be influenced to a greater degree by material variability. It is therefore important that investigations are undertaken to examine the achievement of construction practises and to identify problems which may subsequently arise in control testing.

3.4 Road performance and the development of new specifications

The success of the alternatives and their suitability also depends on behaviour under traffic. Factors which influence this include the moisture conditions in pavement, as a result of climate, drainage or design factors and of road maintenance. In conducting studies of the behaviour of road-making materials a number of alternatives exist to compare performance. On a relative basis, laboratory testing can be used to give an overall ranking of the materials. This procedure however depends on both the applicability of the criteria used to identify satisfactory materials and confidence in the suitability of the tests. The tests themselves have usually been adopted from existing practise and are partly used for identifying similar materials and determining variability (eg classification tests) whilst some can be used to predict field behaviour (eg. strength tests). The latter group therefore fit into the category of performance tests. The problem associated with them is the assumption that the loading applied, the materials condition at the time of test and the criteria used to assess the results reflect those found in the road. It is reasonable to assume that in the past empirical methods developed from experience of field use and the adoption of suitable tests arose from this. It is also well known that the derivation and subsequent improvement of specifications has been as a result of gradual changes to acceptable specifications. The derivation of more radical specifications therefore often requires the evidence of field behaviour.

In examining field behaviour two choices exist. Either existing roads can be studied or special lengths of road may be constructed, as full-scale experiments, on the main road network. In the more developed countries, a further choice may exist and involves the use of a heavy vehicle simulator (13) to apply accelerated loading, usually on parts of the existing network. The implementation of such a system is likely to be beyond the budget of most developing countries. For the study of marginal quality materials existing roads have limitations since only in a few cases would these materials have been used. Their use is limited to examining the performance of acceptable designs and in this respect they have been successfully employed in the determination of road deterioration relationship eg. TRRL RTIM2 and HDM III (9) (14). Only in a few cases have results of a detail suited to adjusting material specifications been obtained from examining the causes of failures in these roads (15 (16).

The Overseas Unit has, for its studies of marginal quality materials, chosen to construct and monitor full-scale road experiments constructed usually as part of new contracts on the main road network of a number of countries. These allow the maximum choice in the number of experimental variables to be chosen in advance and in the control of construction. They also allow a greater choice in terms of the road and climatic environment. In designing a full-scale road experiment, the number of combinations will often be limited by financial constraints and the cost of continually imposing new designs, materials and work practises. In reality this should not be a major obstacle since on a practical level the options should be limited to economic and viable alternatives. It is also often preferable only to examine a few options with sufficiently large difference between them. This would typically involve examining variations in the strength, soils classification, thickness and composition of the different layers, the surfacing design and the maintenance input. In order to obtain results within a reasonable length of time, full-scale trials should be built on roads carrying higher traffic flows than the routes where the results will be applied. Monitoring should be done using quantative methods to enable comparison with existing practices and a variety of techniques exist to do this (17). For specific measurements, alternative methods ranging from high to low capital cost exist.

4. TRRL STUDIES OF MARGINAL MATERIALS

Over the past ten years TRRL have conducted studies into the use of marginal materials in which the strategy described above has been followed. The studies have been performed in collaboration with overseas government organisations and have led to the examination of a wide range of materials in full-scale road experiments. Other aspects, including occurrence and laboratory properties, were also examined. The results of two of the studies are described below and specific characteristics of the materials used are related to their behaviour in laboratory tests and in the road.

4.1 Volcanic-derived gravels in Ethiopia.

In this study the range of types of materials which occur in the Rift Valley have been examined. They include volcanic cinders, tuffs, agglomerates and quarried rhyolite. The study (18) (19), part of which is described below, concentrated on the occurrence and use of cinders.

4.1.1 Definition of volcanic cinders. Volcanic cinders are pyroclastic materials associated with recent volcanic activity. They occur in straight sided cone-shaped hills. The cinders vary in colour, often within the same cone and may be red, brown, grey or black. Their particles vary in size from large irregular shaped lumps up to 500mm in diameter to sand and silt sizes. In some cones, however, they may be more uniform with the largest size not exceeding 30mm in diameter. Other characteristic features are their light weight, their rough vesicular surface and their porosity. They also exhibit a wide range of particle hardness and the softer cinders can be weak enough to be crushed under the heel. An advantage as a road construction material is the relative ease with which they can be excavated; a front-end loader or hand tools are usually adequate although a bulldozer may be required for opening up a working face.

4.1.2 Occurrence and mapping. In Ethiopia cinder cones were found to be concentrated in the Rift Valley (Figl) which extends southwards into Kenya and Tanzania. Their distinctive shape made them easily identifiable on aerial photographs and these were used in planning and conducting the field work in a sample area and in compiling a map of quatenary volcanics in Ethiopia used as the basis for Fig 1.

Exposed profiles in existing quarries showed that a weathered zone extended to a depth of up to two metres. Below this level the material was much more uniform. The size of the cones varied in height up to 100 metres and the largest cones were estimated to contain up to 1 million cubic metres of material.

4.1.3 Engineering properties.

4.1.3.1 Natural cinders. These display a wide range of gradings as illustrated in Fig 2. The materials taken from below the weathered zone are usually too coarse and contain insufficient fine material for use as roadbase material. Their coarse particles are relatively soft and were found to possess dry modified aggregate impact values (20) in the range 46 to 177. On soaking no loss in strength occurred. In the past because of these properties they were rejected for use in roadbase construction. In addition they were also reported to be difficult to compact and when compacted they possessed an open texture or a loose surface which was considered unacceptable for surfacing. However, investigations of the use of cinders in existing gravel roads showed that an improvement in grading occurred as a result of particle breakdown caused by traffic. In order to examine more closely the role of particle breakdown and grading on their behaviour, laboratory compaction studies were conducted using normal falling-rammer methods (21). These found that improvements to their grading occurred as shown in Fig 3. They also showed that cinders may not possess a well defined optimum moisture content (see Fig 4). The test programme was extended to examine the effect of repeated compaction in which a single sample was used for all points in the determination of a compaction moisture/density relationship and the grading of the material measured after each cycle. The results of this, which are illustrated in Figs 5 and 6, led to an improvement in overall grading and gave higher density and CBR values with definite maximum values. This indicated that depending on the amount of breakdown which could take place during field compaction then the material could be improved.

4.1.3.2 Mechanical stabilisation. Although it was shown that compaction could improve the material there was still a deficiency in the fine fraction, ie material less than 75 microns. A further series of tests were therefore carried out in which 10 per cent of locally occurring volcanic ash soil (by volume of the cinders) was added. This resulted in a further increase in the unsoaked CBR and in density. Soaking in water for a period of four days, however, reduced the values to those for the cinders without fines added. The ash soil (a clayey silt) occurs as the natural subgrade in areas of cinder cones hence it use has practical application.

4.1.4 Performance studies. As a result of the laboratory investigation it was decided to conduct this part in two stages. Firstly, to examine methods of compacting cinders and the effect of introducing ash soil and secondly, to construct a full-scale road experiment to examine the performance under traffic of the alternative materials and construction methods.

4.1.4.1 Pilot-scale compaction studies. These examined the following conditions:

(i) Crushed and uncrushed cinders.
(ii) With and without added fines.
(iii) With and without added water.

In the studies a range of cinders were examined including a coarsely-graded cinder, a uniformly-graded cinder and a well-graded cinder. The compaction plant used included a 10-tonne smooth wheeled roller, a 7-tonne vibrating roller and a 10-tonne pneumatic roller.

The results of the trials showed that of the types of cinder examined only the uniformly -graded cinder could not be successfully compacted. For the other cinders, higher densities were achieved. They also showed that in order to obtain a satisfactory surface finish it was important that the cinders contained sufficient fines or were compacted with water. It was concluded that a combination of 2 passes of a pneumatic roller followed by 12 passes of the smooth wheeled roller produced the best compaction results.

4.1.4.2 Full-scale experiment. In the experiment the following materials were examined as road bases:

(i) a well graded cinder,

(ii) a typical cinder with and without fines added,

(iii) a crushed, coarsely-graded cinder,

(iv) a graded crushed stone,

(v) a dry-bound macadam base,

(vi) a tuff,

(vii) an agglomerate.

They were laid in a thickness of 150mm on a pavement comprising a 150mm thick cinder sub-base placed on a compacted ash subgrade. Surfacing comprised a double surface dressing (22). A number of sections were also constructed in which a bituminous macadam was applied as the surfacing. The crushed stone base, a rhyolite, represented standard construction. The dry-bound macadam base was included as a cost saving measure and is a traditional form of construction which has been used for many years in the United Kingdom (23) and which is particularly suited for use in areas where water supply is a problem. It consists of several layers of single-sized roadstone of 37.5, 50 or 75mm nominal size into which well-graded, fine aggregate is vibrated.

4.1.5 Road performance. The experiment was monitored for a period of over seven years. During this time it carried 440,000 equivalent standard axles (ESA) in the more heavily trafficked lane. The ADT ranged between 150 and 230 of which approximately 30 per cent comprised buses and trucks. Performance was assessed by surface measurements of rutting, cracking and deflection at yearly intervals. In addition, on a number of occasions measurements were taken of the in situ density and strength of the various layersand samples taken for the determination of moisture content and soils classification.

With the exception of the tuff, all sections surfaced by a double surface treatment have performed satisfactorily (maximum rutting 4mm, no cracking). In that section longitudinal cracking developed close to the pavement edge. This has been attributed to shrinkage in the base. The sections with bituminous macadam surfacings found to develop a high degree of cracking within two years ($>$ 1m/sq.m) and continued to increase to a level regarded as being unacceptable (24). Resealing of the cracked sections by the application of a surface dressing only had a temporary effect in arresting deterioration. It has therefore been concluded that satisfactory performance can best be obtained from the range of cinders examined provided the surfacing remains sufficiently flexible to tolerate high deflections (up to 1.2mm).

4.2 Calcretes in Botswana.

This study resulted from the need to develop mapping techniques and specifications for roadmaking materials in the Kalahari region of Botswana. The region covers almost 75 per cent of the country and the main sources of roadbuilding material are deposits of calcrete. These materials are generally recognised to be very variable and experience of their use has been limited to the better types. However, because these are not widespread it was considered important that a detailed study of calcretes in general be conducted. The results of the research are intended to be used in the construction of 1200 km of road to be constructed in the region in the next decade.

4.2.1 Description and classification. The calcretes which exist in Botswana are the result of a pedogenic soil forming process, in which carbonates of calcium (and often magnesium) have accumulated in the Kalahari sand. Solution and deposition over time have since given rise to a number of calcareous deposits, all called calcrete, varying from loose calcified sand to massive, hard "rock".

In Botswana, a classification of the common calcrete types has been adopted and these are distinct both physically and in their engineering properties. The recognised types are; calcified (or calcareous sand), powder calcrete, hardpan calcrete (including boulder calcrete) and nodular calcrete. They differ by the amount and type of carbonate present and its degree of crystallinity, the proportion and hardness of any gravel sized particles, and degree of induration. A certain amount of fine material, including water soluble salts and clay minerals, may also be present in some calcretes.

4.2.2 Occurrence and distribution. Calcrete deposits occur throughout the Kalahari region of Botswana. In the study they were found to be associated with topographic features of the sand surface such as pans, inter-dune hollows, topographical depressions and former drainage lines, but also occur in association with grey-coloured patches of sand and with rocks near the surface. A classification of these landforms based on characteristics recognised in remote sensing images was devised. Black and white conventional aerial photographs were used to map topographic features associated with calcrete, and Landsat imagery was used to map features showing colour differences. This enabled maps of calcrete occurrence covering a large area of the Central Botswana to be produced and which are suitable for estimating materials resources for road projects.

In the study, it was shown that the better quality calcretes occurred on the terraces (or platforms) surrounding the large pans and that inferior quality material, often covered by up to two metres of sand overburden, was found in most other deposits. The presence of a terrace can easily be identified by viewing aerial photographs through a stereoscope.

The "Photogeological Map of Botswana"(25) was also produced using remote sensing techniques, and illustrates the main surface materials and exposed geology of Botswana. Figure 7 which is based on this map, shows the presence of calcretes and other materials that are potentially suitable for road pavement construction. The remarks in the figure are based on field investigations conducted in the TRRL study (26). The map shows large areas devoid of the harder varieties of calcrete and which pose problems in the location of suitable construction materials for the roadbuilder.

4.2.3 Engineering test properties

4.2.3.1 Common engineering tests. In the study samples were taken from calcrete deposits throughout Botswana. As a result, typical gradings of the four common types of calcrete are illustrated in Fig 8. The range of test values which they possess in relation to a number of standard tests are illustrated in Table 1. In the table comments are made on their use in relation to conventional specifications (27) and their use in full-scale experiments described in this paper.

4.2.3.2 Bearing and shear strength characteristics. A property of calcretes and other pedogenic materials which is reported to result in improved behaviour in comparison with other roadbuilding materials is that of self-cementation. The suggestion is that this occurs through natural wetting and drying cycles found principally in unpaved roads but which may also apply to pavements with thin bituminous surfacings. It is said to be analogous to "hardpan" formation in nature, and takes place soon after construction (6).

In order to investigate this property, samples of different types of calcrete were compacted at their laboratory optimum and their CBR determined after a period of drying and subsequent wetting. The results, which are given in Table 2, showed that no gain in the soaked strength of the materials occurs. Further tests, up to 20 cycles confirmed this. The results in Table 2, however, illustrate the high CBR values which calcretes possess at OMC and when dried. The risk is that with the fine-grained materials substantial losses in strength can take place if wetting up occurs.

Further investigations have since been undertaken to compare the shear strength properties of calcretes and conventional natural gravels.

These examined the effect of testing in three moisture states and provided information on cohesion and internal fricton, the components of shear strength. The results, which are shown in Table 3, are expressed in terms of Texas triaxial class (28). In the table a lower class number relates to a higher quality material. The results show the dependency of the shear strength of calcretes on moisture content and confirm the results of the CBR testing.

They also show that in relation to the control materials whose strength changes very little with moisture content, their suitability as pavement materials will depend on the in situ moisture conditions.

4.2.3.3 Cost saving measures. In the planning of the study two further solutions to aspects of the Botswana environment were identified as possible cost saving measures. They include the suitability of the better quality calcretes for mechanical stabilisation by the addition of local sand (to save on haulage costs) and the compaction of calcretes which possess a high OMC at a lower moisture content. Laboratory tests had shown that soaked CBR values in excess of 80 per cent could be achieved in the laboratory using both these techniques.

4.2.4 Performance studies. As a result of the field studies and the laboratory investigations the material combinations to be examined were identified. These included:

(i) each of the four common types of calcrete.

(ii) the effect of mechanical stabilisation on a good quality calcrete when mixed with an equal proportion of Kalahari sand.

(iii) the effect of compacting a powder calcrete at a moisture content substantially below its laboratory optimum of 32 per cent.

(iv) the effect on long term performance of subjecting a good quality calcrete to natural cycles of wetting and drying prior to sealing.

The experimental sections were surfaced with a double surface dressing. The calcrete bases were laid in a single 150mm layer on a prepared subgrade of uniformily-graded Kalahari sand. The base was continued across the full width of formation and also provided the shoulder material. Control sections were constructed to the standard construction for the adjacent road contract and incorporated mechanically-stable quartzite and granite-derived gravels in the base and sub-base. Further studies examined the stabilistation of the fine-grained calcretes with cement and with lime and these are described in detail elsewhere (29) and in a paper to this meeting (30). At a later date, sections were also built in which two types of "low-cost" bituminous seal comprising a single surface dressing and a sand seal were applied to a nodular calcrete and a powder calcrete.

4.2.5 Road performance. The experiment has been monitored over a period of 8 years during which time it has carried approximately 200,000 ESA in the more heavily trafficked lane. The ADT varied between 200 and 250 of which 20 per cent comprised heavy vehicles (> 5 tonnes unladen weight).

Quantitative methods for the assessment of road condition (see 4.1.5 and Snaith 1985 (17)) and in situ measurements have been taken throughout the life of the experiment. The materials used have been sampled on a number of occasions.

The performance of the experiment has shown that coarsely graded calcretes (BG1 and BG4 in Table 1) with plasticity indices up to 30 perform satisfactorily as untreated base and shoulder materials. The grading of these materials did not change as a result of field compaction. However, a greater difference in performance was observed with the fine-grained types and the following conclusions were drawn:

(i) The performance of a powder calcrete (BG6 in Table 1) used in the base layer, whether compacted at OMC or 12 per cent below, was equal to that of the better types. However, erosion of the unsurfaced shoulder occurred to a level of 50mm below the road surface.

(ii) A plastic calcified sand base (BG7 in Table 1) gave good service for a period of eight years. Following this, failures in the outer wheelpath occurred. These have been attributed to the moisture sensitivity of the material which was activated as a result of poor drainage from the road shoulder. This material did not prove to be a suitable shoulder material and required replacing after 2 years.

(iii) The 50:50 mix of Kalahari sand and nodular calcrete deformed early giving rut depths in excess of 20mm.

(iv) The stabilisation of sections of calcified sand with the addition of cement and with lime did not lead to a gain in strength, only flocculation in the fines occurred. Under traffic, rutting occurred in the outer wheelpaths of both materials at an early date. This indicated that they were less stable than the plastic materials during the same period of trafficking. This has been attributed to their possessing characteristics common to uniform sands and is discussed in detail by Lionjanga et al (29).

The sections constructed using "low-cost" seals required resealing after three years.

As a result of the research detailed specifications have been developed for the use of calcretes in paved roads (29) (31). They take into account both their physical and mineralogical composition and the required surfacing and shoulder design for the different types of calcrete in relation to design traffic levels.

5. SUMMARY AND CONCLUSIONS

It is clear from the results of the studies that a wider range of materials can be used for road bases in lightly-trafficked roads in tropical regions than was previously suspected. This knowledge has been gained from building full-scale road experiments incorporating materials of marginal quality and monitoring them for nearly 10 years. In the two examples described in this paper, the need for research was prompted by a lack of conventional materials in one case, and the high cost of providing them in the other.

The results of the studies have shown that in making use of marginal materials the effect of climate is likely to play a critical role. Other factors such as pavement drainage, method of construction, design traffic level and level of road maintenance also affect their acceptability.

As a result of the studies the following conclusions have been drawn.

1) Modern remote sensing techniques combined with field survey provide a rapid and efficient means of identifying materials resources.

   They can be used on a regional scale for mapping terrain types with the same materials potential or at larger, more detailed scales, where they can assist in pinpointing deposits.

2) The results of soil classification tests when taken alone do not always give an indication of the suitability of marginal materials. With some materials, particularly those of pedogenic origin or of a highly weathered nature, identification tests based on mineralogical composition may need to be used to extend the classification. In certain cases durability testing and petrographic analysis may also be required. It is acknowledged that these tests may be too costly or time consuming and as alternantive simpler tests such as; the methylene-blue dye absorption test for identifying unsoundness, the aggregate pliers test or the modified aggregate impact test for assessing particle hardness and the Collins' method (32) for determination of the calcium carbonate content may be used.

3) In some instances mechanical breakdown of the materials during compaction improved its grading and significantly improved their engineering performance. A similar result occurred by the mechanical stabilisation of coarsely-graded material with the introduction of fines.

4) Evidence suggests that the measurement of shear strength in the laboratory is likely to offer a better means of selecting pavement materials. In the case of calcretes, it demonstrated their potential for high shear strengths at low in situ moisture conditions, thereby justifying their use as an alternative to conventional materials provided they remained well-drained.

If better use is to be made of other apparently sub-standard materials, it is vital that more assessment studies are undertaken using the strategy described in this paper. Such studies are within the capability of regional materials laboratories, provided there is adequate engineering supervision and where full-scale road trials can be incorporated into ordinary road construction projects. Specifications that result from the studies may at first be largely empirical but with experience design can be matched with performance. Such specifications will permit much wider use to be made of more abundant local materials resulting in substantial cost savings. However, when recommending alternative specifications it is important that the total cost of their introduction including any special design requirements and the level of future maintenance is taken into account.

Finally, lateritic gravels and soft sedimentary rocks are examples of materials which occur extensively throughout the tropics which could usefully merit detailed performance studies of the kind described in this project.

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TABLE 1

TABLE 2. Laboratory test properties of some Botswana calcrete related to use in road construction

Sample No	Soil constants			GM (1)	Passing 425 µm (%)	Passing 75 µm (%)	APV (2)	Soaked CBR mod at AASHTO	Calcrete type	Classification according to Botswana Road Design Manual (3)	Use in full-scale road experiments in Botswana
	PI	LL	LS								
FN3	SP	-	-	2.6	20	-	70	172	Hardpan/Nod.	Road base (C4)	Road base: Francistown-Nata experiment (untreated and lime-modified)
FN1	11	-	5.3	2.5	21	-	70	67	Nodular	Subbase (G5) or lime-modified road base	Road base: Francistown-Nata experiment (untreated and lime-modified)
BG1	8	28	3.7	2.2	34	6	23	110	Hardpan	Subbase (G5) or lime-modified road base	Road base: Kanye-Jwaneng experiment
BG4	20	44	8.5	2.1	38	11	53	105	Nodular	Lime modified base	Road base: Kanye-Jwaneng experiment
JS5B	24	50	8.0	2.3	22	8	70	-	Nodular	Lime modified base or sub-base	Road base: Jwaneng-Sekoma experiment
Q91	12	49	8.3	2.3	23	2	43	103	Nodular	Sub-base (G5) or lime-modified base	-
BG6	7	36	2.9	1.9	44	15	6	90	Powder	Selected subgrade (G6)	Road base: Kanye-Jwaneng experiment
BG7	17	41	7.6	1.1	80	20	28	50	Plastic calcified sand	Fill (SG15)	Road base: Kanye-Jwaneng experiment (untreated and lime/cement stabilised)
BG5	19	38	9.0	1.5	70	18	-	42	Plastic Powder	Fill (SG15)	-
Q87	16	39	6.3	1.2	79	8	5	66	Powder	Fill (SG15)	-
JSBG4	26	49	10.6	1.1	73	28	-	56	Calcified sand	Fill (SG15)	Road base: Jwaneng-Sekoma experiment

Notes:

1. For definition of Grading Modulus (GM) $GM = \frac{300 - \text{sum of \% material passing 2.0 mm + 0.425 mm + 0.075 mm sieves}}{100}$
2. APV - Aggregate Pliers Value (Reference 2)
3. Based on material standards and pavement categories in Chapters 5-107 and 5-307 (Reference 27)

TABLE 2

Comparison of strength values determined on three calcretes following different soaking/drying conditions

Material	California bearing ratio (%)				Level of compaction
	Natural (unsoaked)	4 day soak	3 day dry @ 45°C	3 day dry @ 45°C + 4 day soak	
Plastic calcified sand	78	42	154	40	BS 4.5 Kg
Powder calcrete	135	66	311	39	BS 4.5 Kg
	31	10	175	8	BS 2.5 Kg
Nodular calcrete	125	102	325	83	BS 4.5 Kg
	29	32	133	30	BS 2.5 Kg

TABLE 3

Results of Texas triaxial tests on calcretes and quartzitic gravels

Material	Texas Triaxial Class		
	Moisture condition at test		
	After 10 days capilliary soaking	Optimum moisture content (OMC)	At 65% OMC
Plastic calcified sand	4.3	3.4	2.4
Powder calcrete no.1	3.8	3.0	2.0
Powder calcrete no.2	3.8	3.1	1.2
Nodular calcrete no.1	3.8	3.7	2.3
Nodular calcrete no.2	3.9	3.1	1.0
Hardpan calcrete	3.4	3.3	2.7
Quartz gravel no.1	3.6	3.3	3.2
Quartz gravel no.2	3.7	3.5	3.3

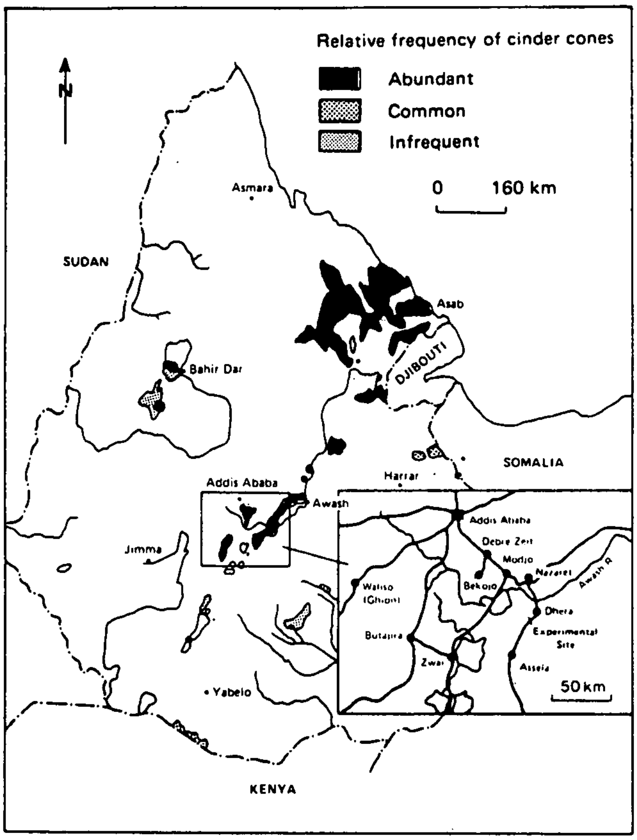

Fig. 1 Cinder cone distribution in Ethiopia, survey area enlarged

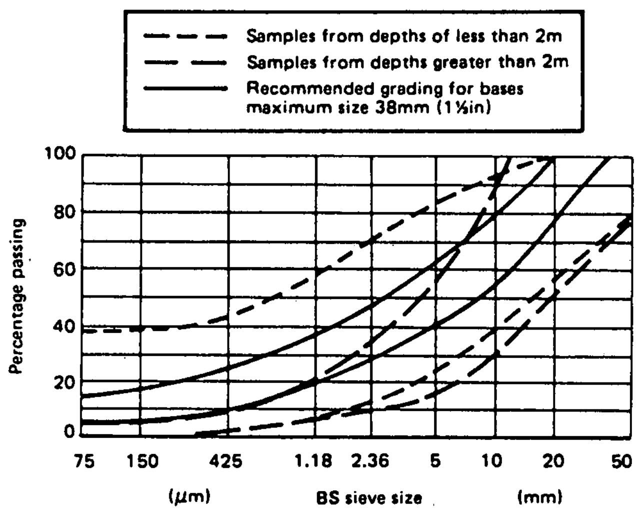

Fig. 2 Gradings of samples obtained during the survey compared with a recommended grading envelope

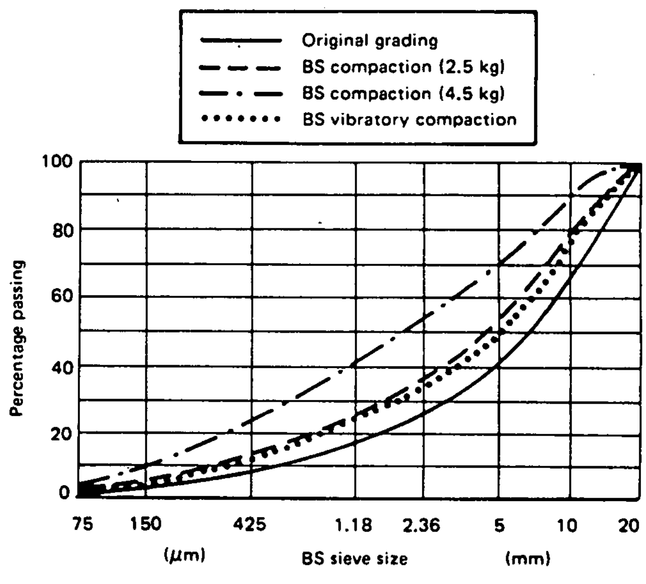

Fig. 3 Effect of compaction on grading—Separate samples used for each point. Each curve is an average of five points

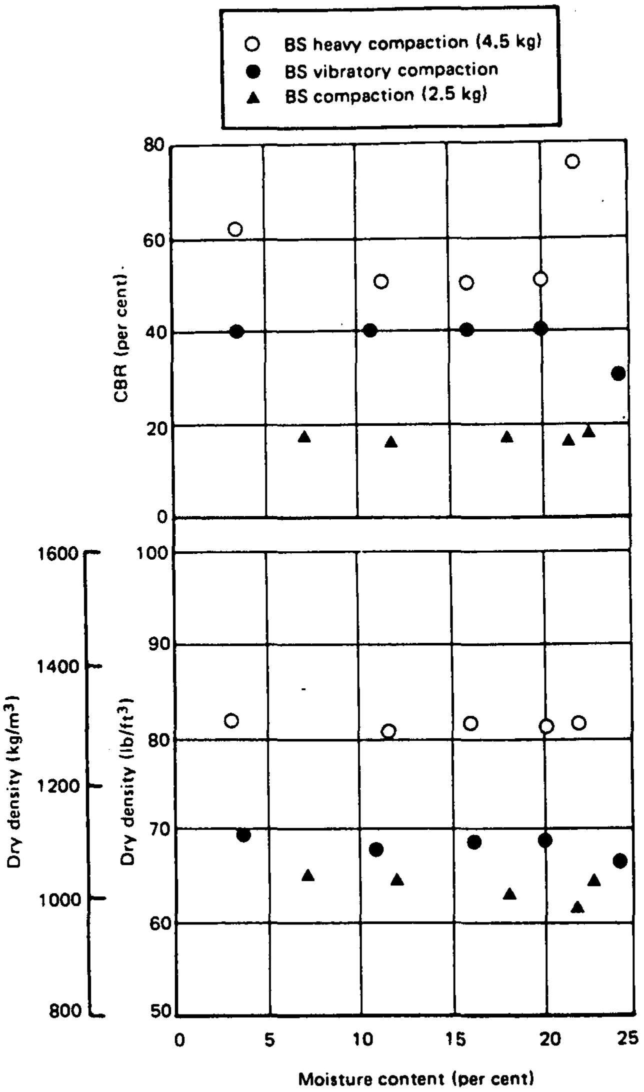

Fig. 4 Dry density/CBR/ Moisture content at different levels of compaction. Separate samples used for each point on the compaction curve

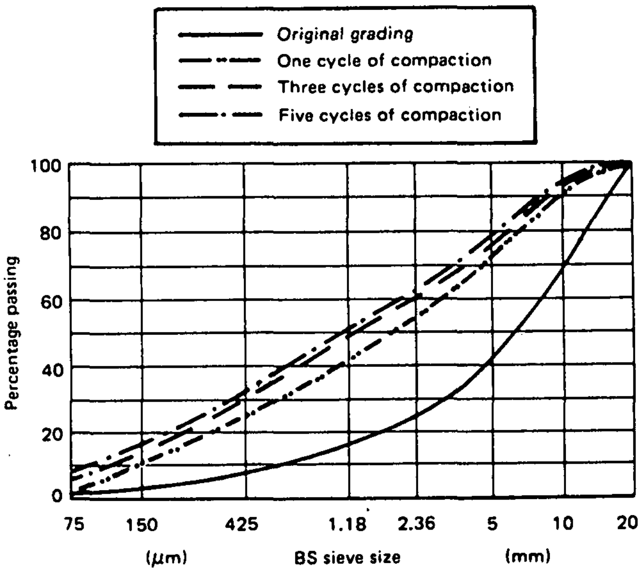

Fig. 5 Effect of repeated compaction on grading, BS compaction (4.5 kg)

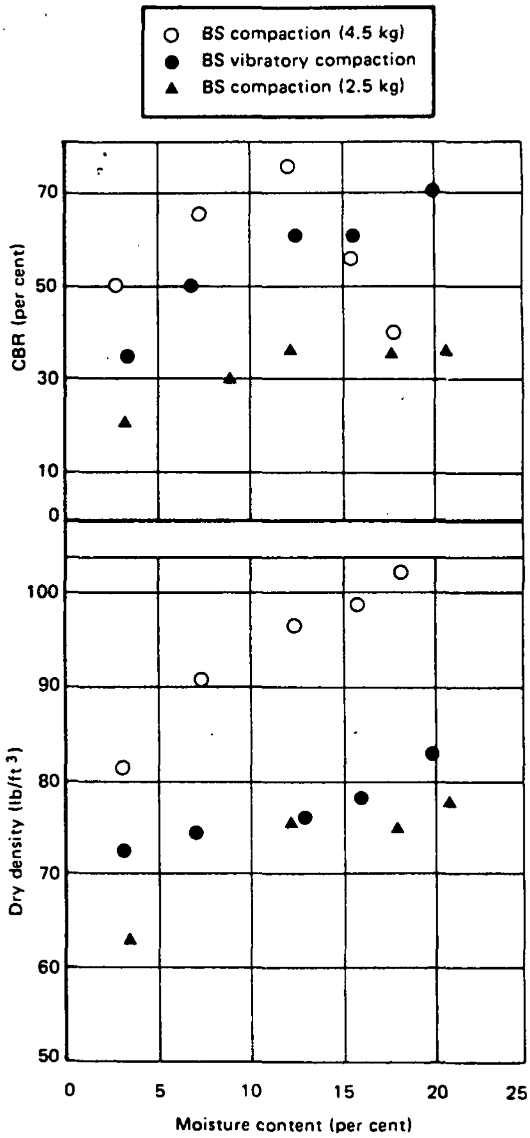

Fig. 6 Dry density/CBR/Moisture content relationship at three levels of compaction. The same sample used at each level of compaction

Key	Geological unit	Calcrete occurrence
	Pre-Kalahari rocks and soils	Few calcrete deposits occur. Natural gravels and weathered rocks abundant
	Kalahari sand areas	Powder calcretes occur in interdune hollows and pans and beneath patches of grey sand
		Poorly developed calcretes occur on fringe areas
	Alluvium	Calcretes may occur between low-lying areas and on former shorelines
	Lacustrine deposits	
	Major areas with calcrete at outcrop or with a very thin sand cover	Hard, pavement quality calcrete occurs. Calcretes also found along river courses
	Distribution limit of most of the major calcrete-rimmed pans	Hard calcretes occur on pan rims. Poorly developed calcretes occur on pan floors and in sand areas

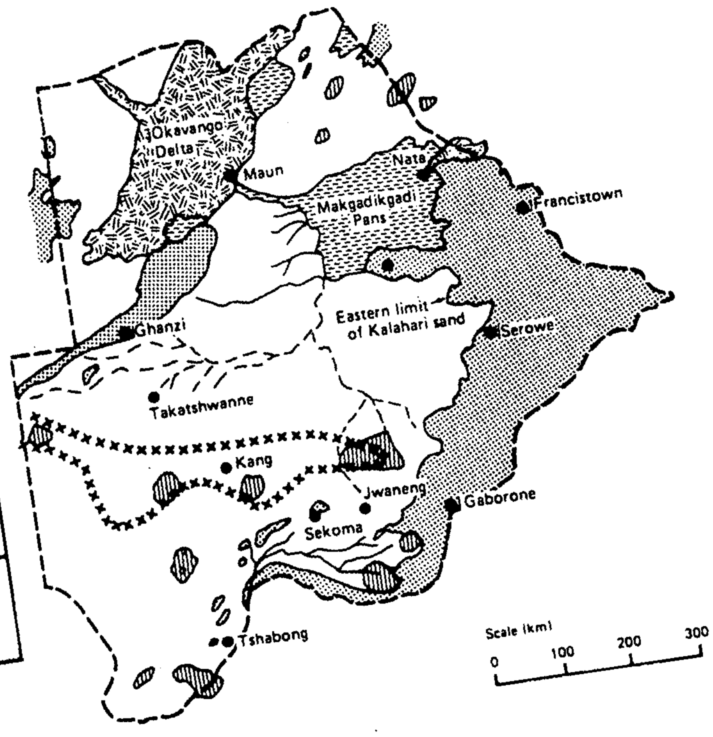

Fig. 7 Distribution of the main material types in Botswana

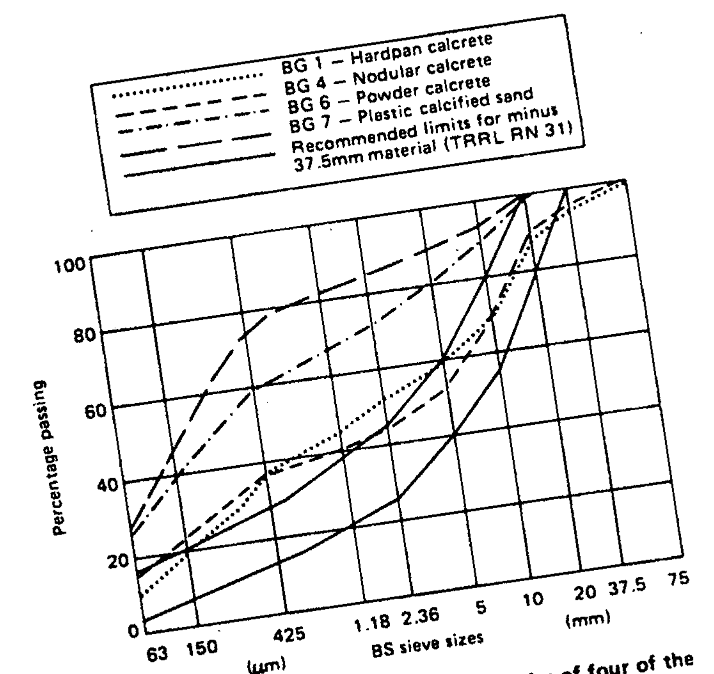

Fig. 8 Mean particle size distributions of samples of four of the common types of calcrete