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SOIL STABILISATION IN AFRICA

by

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ABSTRACT

Excellent and cheap roads have been built in many parts of Africa using stabilised soil for the base and surface-dressings for the running surface.

The most commonly used stabilising agent is cement, but some countries have employed lime stabilisation to great advantage. Bituminous stabilisation is not widely used but is important in several countries that border the Sahara.

The strength criteria that are commonly used to specify stabilised soil in Africa were developed empirically in temperate climates and may not always be valid for use in the tropics. One of the most successful large-scale applications of soil stabilisation in Africa is in Zambia where locally developed CBR criteria are used to specify lime-stabilised gravels.

Research is being carried out at the Transport and Road Research Laboratory into the physical properties of stabilised soil with the object of enabling the cracking of stabilised soil pavements, which is sometimes a problem, to be better controlled. Improved strength criteria based on tensile strength are also being sought.

It is concluded that stabilised soil will continue to play a major role in the development of highways in Africa.

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1. INTRODUCTION

Soil stabilisation may be defined as the improvement of the strength of a natural soil by the addition of a small proportion, normally less than ten per cent, of a stabilising agent. In road construction the purpose is to produce a material which is strong enough to act as a base or a sub-base and which will retain its strength in the presence of water.

The rapid growth in road traffic after the end of the second world war produced a demand for more bitumen surfaced roads all over Africa.

In many countries the natural road building materials traditionally used for unsurfaced roads were found to be unsuitable for constructing bituminous surfaced roads. For example the widely occurring lateritic gravels which make excellent gravel roads proved to be too plastic and too variable to provide a satisfactory road base under a bituminous surfacing.

Engineers soon found that they could make excellent and cheap roads by stabilising the natural materials with cement, lime or bitumen to form the road base and then surfacing it with a 'spray and chip' coat.[1]

Some countries were fortunate (for instance Ghana and Nigeria in West Africa) and found that some of their gravels could be used unmodified for the bases of bitumen-surfaced roads, at least for light and medium-trafficked routes in the drier areas. However in most of the rest of the continent south of the Sahara it was found necessary to stabilise the natural materials and in several countries virtually all the early bitumen surfaced roads built outside the towns had stabilised bases. In Zambia for instance nearly all the existing surfaced roads have lime stabilised bases and some of these have been carrying up to 3000 vehicles per day very satisfactorily since they were first constructed in the early 1950's. The use of crushed stone for road bases was comparatively rare. In many African countries this is still true today, mainly because the relatively large distances between centres of population result in a very 'open' network of roads and there is a very small demand for crushed stone in rural areas other than for roadbuilding itself. This means that if roads are to be built with crushed stone bases and haul distances are not to be excessive a number of small quarries have to be opened up along the route of a new road and closed down again after the road is completed. The cost of this operation is rarely competitive with the alternative of stabilising natural materials which can be found along the route.

2. TYPES OF SOIL STABILISATION EMPLOYED

The most commonly used stabilising agent in the great majority of African countries is cement. Lime and bitumen are also used but to a much lesser extent. Bitumen is usually only employed for stabilising non-plastic sandy soils and thus finds its main application in desert areas, especially in the countries surrounding the Sahara. It is perhaps surprising that lime stabilisation has not been more extensively used than it has been, since many natural gravels occurring in Africa lend themselves to stabilisation with lime and the construction process is in several ways easier to carry out than when cement is used. Zambia and Rhodesia have opted for lime-stabilisation on a large scale but most other countries have tended to use cement in preference to lime. This is probably partly due to the difficulty of obtaining lime commercially in many countries and its relative high price because of the lack of local production facilities. It is not always appreciated that a fairly low quality of lime is satisfactory for soil stabilisation and that it can be produced on a rural industry basis in simple lime kilns. Similarly the construction process of lime stabilised road bases lends itself particularly well to the use of very simple agricultural equipment and labour intensive methods.

For satisfactory stabilisation with lime it is necessary for a soil to possess a clay fraction since the strength of the stabilised material is derived from the reaction that takes place between the lime and the clay particles. The most successful lime stabilisation is achieved with clayey gravels and gravel-sand-clays which have about 15 per cent of material finer than 425 μm (no 36 BS sieve) and a plasticity index of between 10 and 25. Non-plastic soils will not stabilise with lime.

Cement can stabilise virtually all soils that it is practicable to process, provided they are free from gross contamination with organic matter. Soils that cannot be stabilised for this reason can easily be detected by means of the pH test developed by Sherwood.[2] The ability of the available machinery to pulverise soil sufficiently for stabilisation puts a limit on the plasticity of soils that can be processed, and the practical upper limit with powerful machinery is when the plasticity index of the soil multiplied by the percentage of it that is finer than 425 μm (no 36 BS sieve) is greater than approximately 3500. More plastic soils than this can be stabilised in special circumstances by employing pre-treatment with lime for instance, but the feasibility of doing so depends on factors like the field moisture content of the soil and the incidence of rain, and usually only when there is absolutely no other choice is it economic to do so.

Non-plastic soils can be readily stabilised with cement and they also lend themselves to stabilisation with cut-back bitumens. The 'single size' sands (those with a uniformity coefficient less than about three) present a special problem because of their inherent lack of internal friction or cohesion and generally a more satisfactory solution will be found by stabilising them with bitumen than with cement.

Several other agents can be used for stabilising soils such as aniline furfural, sulphite lye, various resins, but these are invariably uneconomic compared with cement, lime or bitumen and are of negligible significance.

3. PAVEMENT DESIGN

The great majority of stabilised soil roads in Arica have bases which are 10 cm to 15 cm (4 to 6 ins) thick with thin bituminous surfacings of the 'spray and chip' type. Sub-bases of untreated gravel with an effective California Bearing Ratio (CBR) of 25 or more are commonly used and only very rarely is it necessary to stabilise material for the sub-base. The overall thickness of construction is usually determined by the application of a simple design method based on the early CBR method devised by Porter.[3]

The main drawback of this approach is that the difference in properties between cement and lime-bound materials and un-bound materials is not taken into account. This means that on the one hand stabilised material may be laid too thinly and thus becomes easily overstressed, whilst on the other hand when laid thicker than say 20 cm (8 ins) advantage is not taken of its somewhat superior load spreading properties as compared with un-bound materials. The latter situation is perhaps not a matter for concern since the insitu processing machinery available puts an upper limit of about 20 cm (8 ins) on the thickness of the soil layer that can be processed in one operation (and two layer insitu construction is rarely undertaken because of the difficulty of ensuring complete stabilisation of the soil at the interface between the two layers). Up to a 20 cm (8 in) layer thickness it is considered that the structural value of stabilised soil is not sufficiently different from high quality un-bound materials to warrant any reduction in the thickness of layer required to carry a given traffic load.

However the dangers of laying stabilised soil bases too thin are real. A 10 cm (4 in) thick base of stabilised soil on a sub-base of CBR 25 material can be badly damaged by the passage of a single heavy wheel load and the evidence is[4] that stabilised soil bases need to be a minimum of 15 cm (6 in) thick if they are to provide satisfactory service.

Pavement design recommendations for roads in the tropics which incorporate this minimum thickness requirement and take into account the numbers and weights of the axle loads applied to the pavement have been published by the Transport and Road Research Laboratory.[5] These recommendations also incorporate the concept of stage construction and give some guidance on the strengthening required for the basic 15 cm (6 in) thick base if traffic grows above a certain level.

4. STRENGTH CRITERIA FOR STABILISED SOIL

The strength criteria that have been used in Africa to design stabilised soil mixtures have usually been based on the empirical criteria that were developed in the temperate climates of North America and Europe. This prompts the suspicion that they may not be valid for African conditions; in particular the need to resist frost penetration is absent in most of Africa and water tables are generaly lower than in the temperate zones.

For soil-cement the most widely used test is the Unconfined Compression Strength test.[6, 7] Acceptable materials for road bases are commonly required to have a minimum unconfined compression strength at an age of seven days in the range of 14 to 53 Kg/cm^2 (200 to 750 lb/in^2) as given by cylindrical specimens with a height/diameter ratio of not more than 2:1 or cubical specimens, compacted to the dry density expected in the field.

Some authorities require that the specimens shall achieve this minimum strength when for part of the curing period the specimens are immersed in water.

The California Bearing Ratio test (CBR) is also favoured in some African countries[8, 9] and has much to commend it for evaluating stabilised gravelly materials that need only small additions of cement or lime. Specimens are normally cured for periods of from three to seven days and are then immersed in water for a further one to four days before testing. Acceptable CBR values range from 100 to 240 per cent depending on the dry density to which the specimens have been moulded. These values correspond to CBR values of 80 to 100 per cent or more at the density expected in the field.

The durability tests developed by the Portland Cement Association[10] (PCA Chicago) are also used for designing soil-cement mixtures. In these tests specimens are subjected to twelve cycles of freezing and thawing or wetting and drying and the allowable loss of material from the specimens in the process is related to the classification of the soil being stabilised.

Whilst the ability to withstand freezing and thawing is clearly very far removed from the demands made on a stabilised soil base by the climatic conditions in Africa, the wetting and drying test perhaps deserves more attention than it has so far received. This test, which in a sense relates to the tensile strength of the material, could be used as a check of the suitability of a soil for stabilisation, the decision on the amount of stabiliser required then being made on the basis of previous local experience of similar soils and the construction techniques used without the need for resorting to strength tests.

But many engineers feel the need for design criteria in terms of strength. For lime stabilised soils both the unconfined compressive strength test and the CBR test are used and similar strengths are normally required as for the soil-cement mixtures. However it is customary to allow a longer curing period before testing to allow for the low rate of gain of strength in the early life of the mix which is characteristic of most lime-soil mixtures. Specimens are occasionally cured for 28 days before testing, the last one to four days of which may consist of immersion in water.

In addition to the strength and durability criteria limits are also often imposed on the particle size distribution and plasticity of the soils to be stabilised, and in some cases a maximum and minimum stabiliser content is specified. These limits ensure that the material selected in the laboratory is capable of being mixed properly by the plant in the field.

For bituminous stabilisation there is even greater uncertainty than with cement and lime stabilisation as to what are the appropriate criteria to apply for designing mixes for tropical conditions, mainly because the fund of experience is very much smaller. The Hubbard-Field test[11] is probably most commonly used, stabilities of the order of 500 to 700 kg at 60°C being required for base materials[12]. There is evidence however that somewhat lower stabilities can be satisfactory[13]. The use of the simple cone stability test has been explored[14] and appears promising, but as with other mechanical tests there is insufficient experience of the performance of mixes in the tropics to derive criteria with any confidence.

The drawback of all these strength criteria (for cement, lime and bitumen) is that they relate only indirectly to the stresses that are critical to the performance of stabilised materials in road bases. For instance the mode of failure of most soil cement bases is tensile cracking and yet the test most commonly used to 'design' the material is the unconfined compression test. The unexpected failure of some new soil cement roads with unconfined compressive strengths that have been judged satisfactory is an indication that the test does not measure the property of the material which is sometimes critical to its performance in a road pavement.

These strength criteria therefore must be regarded more as a means of selecting classes of material that on the basis of past experience can be expected to perform satisfactorily, rather than as a means of designing the strength of the materials.

This underlines the need for care in transferring this sort of empirical criteria developed in one environment to another quite different environment. It is notable that perhaps the most successful large scale application of soil stabilisation in Africa[9] is based on empirical criteria that were developed locally.

Research is in progress at the UK Transport and Road Research Laboratory into the basic physical properties of soil cement.[15] It is believed that a fuller understanding of the tensile and compressive stress-strain properties, and the creep and shrinkage properties of the material will enable better predictions to be made about its performance in roads.[16] The results so far are encouraging in that a relation between the tensile strength of soil-cement and the crack pattern developing in pilot-scale pavement slabs has been demonstrated.[17] This work could lead to the design of stabilised soil mixes on the basis of their tensile strength rather than on compressive, CBR or durability criteria. In the present state of knowledge however, experience in several countries would indicate that the most satisfactory strength criterion for stabilised soil in Africa is that it should have a CBR value of not less than 100 per cent at an age of seven days at a density equivalent to that which it will be compacted to in the field.

5. METHODS OF CONSTRUCTION

Two basic methods can be used for stabilising soil; a) the plant-mix method in which the stabilised material is mixed in a static plant and transported to the laying site in trucks, and b) the mix-in-place method in which the stabilised soil is mixed on the road formation either by multipass or single pass machinery. In the latter method the soil processed may be either the insitu soil occurring along the line of the road, or more commonly it is a selected soil won from nearby borrow pits which is transported and spread on the formation in readiness for the stabilisation.

The static plant-mix method is mostly favoured for airfield construction or other large paved areas where considerable volumes of material are required in one place and the haul distance between the plant and the laying site is short. It is not very often used for road works in Africa. Cement, lime or bitumen stabilised soils can be mixed in static plants, which are usually modified paddle-type concrete mixers or bituminous hot-mix plants. It is difficult to mix soils in static plants if they are not 'free flowing' materials and this means that plant-mix operations are usually confined to soils with low plasticity. A rough idea of the upper limit of soil plasticity that it is feasbile to handle in a static plant may be obtained by multiplying the plasticity index of the soil by the percentage of it which is finer than 425 μm (no 36 BS sieve). If this value is less than 500 the plant mix method should be possible.

The mix-in-place method, which is most commonly used for road construction in Africa, can be undertaken with a wide range of plant, ranging from simple agricultural machinery to high powered single-pass stabilising machines. The various types of mix-in-place plant available can conveniently be classified into four groups:

i) agricultural disc harrows, agricultural disc ploughs, and motor graders,

ii) 'light' rotavators with less than 100 hp engines

iii) heavy-duty rotavators with greater than 100 hp engines (often called 'Pulvimixers')

iv) single-pass soil stabilisation machines (normally powered by at least 100 hp engines).

This classification represents increasing capital cost and output per unit in ascending order from group i) to group iv). The correct choice of equipment for a particular project will depend on many factors, mainly of an economic nature, but the plasticity of the soil to be processed can also influence the decision. The upper limits of soil plasticity that it is practicable to process with the various types of plant are indicated in Table 1.

TABLE 1

Soil plasticity limits for stabilisation using different types of plant

Type of plant	Plasticity index of the soil multiplied by the percentage finer than 425 μm (no 36 sieve)	Normal max depth capable of being processed in one layer - cm
Agricultural disc harrows disc ploughs etc and motor graders	$\ngtr$ 1000	12 to 15
Light rotavators (< 100 hp)	$\ngtr$ 2000	15
Heavy duty rotavators (> 100 hp)	$\ngtr$ 3500	20 to 30 depending on soil type and horsepower available
Single pass stabilisers	$\ngtr$ 2000 to 3000 depending on the horsepower	20
Static mix plant	$\ngtr$ 500	no limit

In mix-in-place stabilisation with cement or lime the stabiliser can be spread on the loose soil either by hand or by a mechanical spreader. More even distribution can be obtained with mechanical spreaders than by hand methods which means that the maximum practical rate of spread of the stabiliser can be somewhat lower. With efficient mechanical spreaders it is possible to employ stabiliser contents as low as one per cent but with hand methods the practical minimum is about two per cent.[18]

When stabilising soils with cement or lime it is usually necessary to add water to the pulverised soil to bring it to the correct moisture content for compaction and provide adequate water for hydration. The moisture content of the mixed soil should normally be within one or two per cent of the optimum moisture content of the soil/stabiliser mix in the standard laboratory Proctor compaction test, (BS 1377:1967 Test 11[19] or AASHO test T-99), but with light sandy soils in severe drying conditions extra water may be needed to counter the rapid evaporation that can occur before the soil is compacted. The water is added directly into the mixer in the case of plant-mix operations or is sprayed on to the loose soil with water bowsers in mix-in-place operations. Most purpose-made mix-in-place pulvimixers have provision for adding the water through a metering pump and spray bar under the mixing hood so that the amount added can be accurately controlled and waste is minimised. Similar spraybars are used for adding the bitumen when the mix-in-place method is employed for bituminous stabilisation.

The compaction and shaping of stabilised road bases is carried out with the normal rollers and graders that are used for many other construction processes. When the final shaping is complete some form of curing is required for cement and lime stabilised bases. This is usually provided by regularly spraying the base with water, covering it with damp soil, or applying a bituminous curing membrane.

The practice of using very fluid cut-backs (MCO or MC70 grades) for combined curing membranes and prime coats for surface dressing the base is not advocated since they provide a poor barrier to the escape of moisture and it is possible that the fluxing oils in them may adversely affect the hydration of the stabilised soil at the surface of the base. Similarly it is possible that repeated spraying with water may be deleterious in some circumstances (such as with sandy soils) in that it may tend to wash out the stabiliser and soil fines from the upper surface of the base. These aspects of curing are currently being investigated in research at the UK Transport and Road Research Laboratory.

6. FAILURES OF STABILISED SOIL ROAD BASES

As with all road construction processes there will be problems if the proper techniques for building stabilised soil roads are not employed, although in many respects the material is more tolerant of misuse than some of the alternatives. However it is useful to examine the various modes of failure that can occur with stabilised soil and discuss how they can be avoided.

The failure of cement or lime stabilised road bases can occur in three main ways, by cracking, by deformation, or by the disintegration of the stabilised material into a loose granular mass. Deformation is inevitably preceded by cracking but the cracks may not always be visible at the road surface. The breakdown of the stabilised material into a loose mass can result in a fourth symptom of failure, the stripping-off of thin bituminous surfacings under the action of traffic.

By far the most common form of failure is cracking failure, and indeed this is so common that most engineers would not rate the presence of visible cracks as an instance of failure unless they are accompanied by significant deformation. It is generally accepted that a certain amount of cracking in stabilised soil bases is inevitable and that even when such cracks reflect through a bitumen surfacing they are not important as long as they are sufficiently small to enable load to be transferred across them and to prevent water from easily penetrating them. Of course if there is a plastic subgrade underneath and the cracks are big enough to let surface water through the pavement will 'fail' because of subgrade deformation.

From time to time there are spectacular cracking failures of newly constructed roads (notably sand-cement ones) which have given stabilised soil an undeservedly bad reputation in some countries. The cause of failures of this type is very likely to be due to the use of inappropriate strength criteria for the design of the stabilised soil, coupled perhaps with an unwise choice of the material being stabilised. It is hoped that the current research into the tensile properties of soil cement that has been mentioned earlier will enable the worst of these cracking problems to be avoided in future. The dilemma is that if sufficient stabiliser is added to give certain stabilised soils adequate durability and strength, large 'shrinkage' cracks appear in the base at regular spacings a short time after the completion of the construction. These cracks are too large to enable load to be transferred across them and they quickly reflect through thin bituminous surfacings. However with a knowledge of the tensile strength of the stabilised soil (and its rate of gain with age and other factors), it is possible to pre-crack a base to a desired crack pattern by applying a specific wheel load at a certain time. If for instance cracks are induced at say 0.5 m intervals they will be very small with a good interlock and appropriate bituminous surfacings will be able to accommodate the small differential movements across the cracks. Moreover adequate stabiliser can be put into the stabilised soil to provide a good resistance to attrition at the cracks without the fear of the large 'shrinkage' cracks forming. When designed and laid in this way a stabilised soil base can properly be regarded as a 'flexible' base akin to crushed rock or gravel, rather than as a rigid base with characteristics like concrete.

Another reason for cracking failure in stabilised soil bases is simply inadequate construction thickness in relation to the traffic and the subgrade strength. This applies to all road base materials of course, but the resulting failures tend to be more obvious with bound materials than with un-bound materials and are more often wrongly attributed to deficiencies of the material rather than to the thickness. When cement and lime stabilised bases are constructed only 10 or 12 cm (4 to 5 ins) thick they will need only very few passages of medium sized trucks to crack them. Even when they are laid 15 cm (6 in) thick, as with any other type of base, they may show signs of failure if the level of traffic grows significantly above 150 to 200 trucks per lane per day, (or if they receive a cumulative total of more than half a million 8 200 kg (18000 lb) equivalent axles per lane).[5]

It seems likely that many of the roads in Africa that were built with 15 cm (6 in) thick stabilised soil bases in the early nineteen sixties have already carried their full design quota of traffic with only one or two surface dressings for maintenance and they are now in need of strengthening on the basis of pavement thickness.

It is preferable to strengthen them before they deteriorate to the stage where complete reconstruction is necessary since this is clearly more expensive and it is difficult to salvage much from a badly damaged stabilised base. A careful watch on the rate of growth of deformation, cracking and deflection will provide a good warning of the critical time to act.

The failure of stabilised soil by disintegration into a loose mass is not very common and is most likely to be due to deficiency in the amount of stabiliser, deficiency in the quality of the stabiliser, or deficient compaction or curing. Soil stabilisation needs a considerably higher level of site supervision than the laying of crushed stone for instance and if the supervision is lacking a common sort of fault that occurs is that parts of the base receive little or no stabiliser and the depth of processing is allowed to vary erratically. Both of these faults tend to produce local failures in which the stabilised soil breaks up and crumbles away.

A more common type of failure is the peeling-off of surface dressings from stabilised soil bases. This is more often than not an indication of the failure of the top of the base rather than of the surfacing itself. The surface of the base tends to disintegrate under traffic most likely as the result of overstressing of the surface layer during the compaction of the base material at the time of construction. This induces a series of shallow shear planes in the surface layer and results in a sharp falling off in the density of the material towards the upper surface. 'Overstressing' is most prevalent with non-cohesive sands, especially the 'single-sized' variety but it can be avoided if special care is taken with the compaction and towed vibrating rollers are used.

When the surface of the base is sound there is no reason why surface dressings should not adhere completely satisfactorily to stabilised soil bases. A prime of M.C.70 applied at a rate of 0.7 to 1.1 litres/m^2 (after the initial curing is completed) should ensure this.

The mode of failure of bituminous stabilised bases is nearly always by deformation which is simply a symptom of inadequate stability in the mix. If the failure is localised it is probably due to a variation in the bitumen content or a variation in the grading of the soil being stabilised.

7. CURRENT ATTITUDE TOWARDS SOIL STABILISATION

In order to assess the current attitude towards soil stabilisation for roads in Africa a questionnaire was recently circulated to a number of African countries. Full replies or partial information was received from sixteen countries, representative of the whole of the continent.

Information from eleven countries is summarised in Table 2. These eleven countries possess about 82 000 km of bituminised road of which about half (42 000 km) have stabilised bases. However the proportion with stabilised bases falls to about one-third if Algeria is not included in the list since it has an unusually high proportion of bitumen-stabilised roads.

Most of the countries appear to have been well served by stabilised soil roads except for Kenya which reports a high incidence of unsatisfactory performance with cement and lime stabilised bases and which is in the process of reconstructing 500 km of stabilised soil road. On the other hand virtually all the bitumen surfaced roads in Zambia have stabilised soil road bases and their performance is very good, and several other countries report nil failures with stabilised soil.

In the French speaking countries of West Africa stabilisation with bitumen is very popular and south of the Sahara cement is the principal stabiliser used. The use of lime stabilisation is not as widespread as its good results would appear to justify, and benefits could be gained if it were used in more countries.

Some countries limit the use of stabilised soil to light and medium-trafficked roads, whilst others look upon it as a high quality material which can only be justified even on the main roads when the natural gravels available are sub-standard.

TABLE 2

Soil stabilisation practice in eleven African countries

Country	Km of roads with stabilised bases	Km of bitumen surface roads	Cement stabilisation: Specification(s)	Cement stabilisation: per cent stabiliser normally used	Cement stabilisation: Km of road base stabilised	Cement stabilisation: Per cent failure	Cement stabilisation: Type of failure	Lime stabilisation: Specification(s)	Lime stabilisation: per cent stabiliser normally used	Lime stabilisation: Km of road base stabilised	Lime stabilisation: Per cent failure	Lime stabilisation: Type of failure	Remarks
Algeria[1]	30 000	40 000	French Specification	5 to 7	100	-	-	French Specification	1 to 3	1000	-	-	Bitumen stabilised bases preferred for heavy traffic
Angola	1 500	6 000	Durability test UCS & grading	3 to 8	1500	nil	-	-	-	-	-	-	Soil stabilisation used when costs are in its favour
Gambia	165	3000	Density spec no strength spec	3	165	nil	-	-	-	-	-	-	Soil stabilisation used for new main roads
Ghana	135	3 800	UCS 1.7 MN/m^2 @7 days & CBR 200	4 to 5	135	nil	-	-	-	-	-	-	Soil stabilisation for major projects only, natural gravel normally used
Kenya	1 440	3 100	UCS 1.8 MN/m^2 PI$\not>$6	4 to 6	1290	20 to 40	Cracking, stripping and deformation	As for cement	3 to 7	150	77	Cracking stripping and deformation	Soil stabilisation not favoured - only used if alternatives significantly more expensive
Mozambique[2]	1 154	2 780	UCS 1.7 MN/m^2 Durability test	6 to 9	896	0.5	Cracking, deformation & stripping	CBR > 80 PI $\not>$ 6	2 to 4	110	nil	-	Soil stabilised bases limited to medium and lightly trafficked roads
Nigeria[3]	800	12 500	CBR 160-180 field CBR 80-100	4 to 7	720	15	”	As for cement	-	nil	nil	-	Soil stabilisation only used when suitable natural gravels unobtainable
Rhodesia	1 700	3 500	Texas triaxial $\not>$ 3.0) natural PI $\not>$ 6) material UCS 700 KN/m^2	2	1500	nil	-	Texas triaxial $\not>$ 3.0) natural PI 6 to 12) material	2 to 4	200	nil	-	Soil stabilisation preferred when costs comparable with alternatives
South Africa (Orange Free State only)	1 600	4 300	UCS 3 to 5 MN/m^2 Grading & PI limits	3 to 5	1600	5 to 20	stripping	-	-	-	nil	-	ditto
Tanzania	800	2 500	UCS 1.7 MN/m^2	5	640	10 to 20	cracking & deformation	Standard percentage no strength test	5	160	nil	-	ditto
Zambia	3 000	3 000	CBR 180 Grading & PI	3 to 4	approx 1000	nil		As for cement	4	approx 2000	nil	-	Soil stabilisation used for all main roads

1 Algeria also has 28000 km of bitumen stabilised road base (with 3 to 8 per cent of 80/100 bitumen), deformation and stripping affecting about 20 per cent of the total length. (Hubbard Field test is used to design the mixes).

2 Mozambique also has 148 km of bitumen stabilised road base (with 5 to 6 per cent bitumen), no failures are reported (Hubbard Field test is used to design the mixes).

3 Nigeria also has 70 km of bitumen stabilised road base (4 per cent bitumen) deformation is reported to affect 2 per cent of the length. (Hubbard Field test was used to design the mix).

The majority verdict on soil stabilisation is overwhelmingly in favour and it appears to compete favourably on cost grounds with alternative forms of construction for bitumen surfaced roads throughout most of Africa. Of course where natural gravels can be found which are good enough for making bitumen-surfaced roads this will be the cheapest form of construction.

The difference in the performance of stabilised soil in different countries however does warrant further investigation of the properties of the material which may perhaps lead to more satisfactory strength criteria.

8. CONCLUSIONS

1) Stabilised soil will continue to play a major role in the development of the highways of Africa as it has done in the past.

2) Empirical strength criteria for stabilised soils that were developed in temperate climates should be examined carefully when being applied in Africa.

3) A better understanding of the physical properties of stabilised soil should help to prevent the misapplication of existing strength criteria and may produce more satisfactory criteria in the future.

4) Lime stabilisation has advantages in the simplicity of the construction procedure. That it is not more widely used probably derives from supply difficulties with lime being marketed at a price equal to or even above that of cement. There are potentialities in developing local industries to produce lime more cheaply and not necessarily of high quality.

5) More information is required on the effects of the various curing measures that are employed for cement and lime stabilised soils, and more information is needed on the design of bituminous stabilised soils.

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ABSTRACT

Soil stabilisation in Africa: J N BULMAN: Department of the Environment, TRRL Report LR 476: Crowthorne, 1972 (Transport and Road Research Laboratory). Excellent and cheap roads have been built in many parts of Africa using stabilised soil for the base and surface-dressings for the running surface.

The most commonly used stabilising agent is cement, but some countries have employed lime stabilisation to great advantage. Bituminous stabilisation is not widely used but is important in several countries that border the Sahara.

The strength criteria that are commonly used to specify stabilised soil in Africa were developed empirically in temperate climates and may not always be valid for use in the tropics. One of the most successful large-scale applications of soil stabilisation in Africa is in Zambia where locally developed CBR critieria are used to specify lime-stabilised gravels.

Research is being carried out at the Transport and Road Research Laboratory into the physical properties of stabilised soil with the object of enabling the cracking of stabilised soil pavements, which is sometimes a problem, to be better controlled. Improved strength criteria based on tensile strength are also being sought.

It is concluded that stabilised soil will continue to play a major role in the development of highways in Africa.

This report was prepared as a contribution to the Second African Highway Conference organised by the International Road Federation in Rabat, Morocco, April 1972.

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