PRELIMINARY STUDIES ON THE UTILISATION OF BEREA RED SANDS FOR SUB-BASE AND BASE CONSTRUCTION

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ABSTRACT

Berea Red sands occur in abundance on the eastern seaboard of KwaZulu-Natal and Mozambique.

The material is of Aeolian origin and is seldom used as base and sub-base material in the region, even on lightly trafficked roads. The main reasons for the material being discarded revolve around the supposed variability of the material and it being supposedly substandard.

However recent studies, undertaken by the CSIR[4], have shown that although the material has certain limitations e.g. Grading Modulus (GM), it is the lack of knowledge about this material which is the main shortcoming.

The paper presents preliminary findings of the investigations on the utilisation of Berea Red sands in the construction of sub-base and base layers in roadworks

The investigations and studies have shown that Berea Red sands:

- Are no more variable than most sources of natural gravels obtained from borrow pits or construction cuttings. What has lead to some confusion is that all the “sandy material” along the east coast has been referred to as “Berea Reds” irrespective, of the colour of the sand, and
- Can be economically modified/stabilised/physically changed to make them suitable for use both as a sub-base and base layer for road works.

In addition from cores, taken as part of the study, from roads constructed in three different areas, it is quite clear that the lime stabilised Berea Red material used in sub-base and base construction, is in a surprisingly good condition after a period of some 30 – 40 years (there have been authorities that have claimed that lime stabilisation is not of a permanent nature).

1. BACKGROUND AND INTRODUCTION

With the rapid development and urbanisation, specifically along the east coast regions of KwaZulu-Natal, sources of natural gravels for road building materials are becoming scarce. The easy route of using crushed aggregate instead of natural gravels for sub-base and base construction instead of natural gravels is also causing undue escalation of road construction costs and the depletion of limited natural resources.

“Berea Red” sands occur extensively along both the South Coast and North Coast of

South Africa into Mozambique for a wide strip of some 20 – 30 Km from the coast into the interior.

The “Berea Reds”, as they are locally known, have not been extensively used for sub-base and base construction for various reasons, among them that the material generally has a Grading Modulus (GM) of less than 1 and is too variable. They do fall between G6 and G8 classification according to TRH4 (1985) or A-2-4(0) to A-6( ) if classified according to the AASHTO classification.

It is normal practice to investigate any natural source of gravel to establish the quality, quantity and so variations in the material properties. From the investigations carried out over the period between 2005 to 2007 it became quite clear that the “Berea Reds” are no more variable than any other natural gravels.

What has probably led to some confusion, however, is that all the “sandy material” along the east coast has been referred to as “Berea Reds” irrespective of the colour of the sand which can vary from light yellow to orange and light to dark brown or dark red.

2. SAMPLING AND INVESTIGATION [4]

2.1 Sampling of the material

Some 22 samples were taken from 6 sites along the A5092 and A5094 roads in the La Mercy/Ballito area along the eastern seaboard of KwaZulu-Natal.

2.2 Testing of the material

The physical tests namely Atterberg limits and grading were carried out on all 22 samples and the samples classified according to the AASHTO classification. Fifteen of the samples fell in the A-2-4(0) group, 5 in the A-6 group and one each into the A-2-6(0) and A-4(1) group classification.

For economy reasons the physical properties and gradings of the samples were examined and similar samples grouped together. This resulted in the 22 samples being reduced to 6 typical samples. These 6 samples were again graded to obtain the resultant physical properties and gradings.

The 6 samples were subjected to the following tests:

- CBR tests on the “neat” samples;
- CBR tests on the A-6 ( ) material stabilised with lime;
- CBR tests on all A-2-4(0) material modified with different percentages of crushed aggregate (this was done to improve the GM of the non-plastic material, and
- CBR tests on the A-2-4(0) material modified as described above to improve the GM stabilised with small percentages of stable grade emulsion and cement.

2.3 X-ray diffraction analysis and comments

The 6 samples were also submitted for X-ray diffraction analysis to establish if there is any basic material difference between these samples

A summary of the X-ray diffraction analysis (XRD) results as well as the physical test results of the six samples as well as 2 samples from Mozambique[6] are summarised in

Table 1 below.

Table 1 Summary X-ray diffraction analysis and physical tests

Sample No.	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	A	B
Classification	A-2-4(0)	A-2-4(0)	A6(1)	A6(1)	A-2-4(0)	A-2-4(0)	A-1-b(0)	A-1-b(0)
Grading Modulus	0,95	0,85	0,78	0,88	0,95	0,96	>2.5	>2.5
Plasticity Index.	N.P.	7.6.	14	17.68	N.P.	N.P	1,3	S.P
X-ray Analysis								
Illemenite	1%	1%	-	-	1%	1%	-	-
Goethite & Hematite	-	1%	2%	4%	-	trace	4%	3%
K-Feldspar	1%	1%	2%	-	-	-	3%	3%
Quartz	98%	92%	87%	83%	98%	99%	84%	84%
Mica	-	1%	-	-	1%	-	6%	2%
Kaolonite	-	2%	6%	9%	-	-	3%	3%
Illite/Smectite	-	2%	3%	4%	-	-	-	--
Plagioclase	-	-	-	-	-	-		5%

Samples A and B were taken from the centre of a road in Mozambique[6]. These samples had been modified with coarse material resulting in CBR values of 130 – 170 at 100% Mod AASHTO.

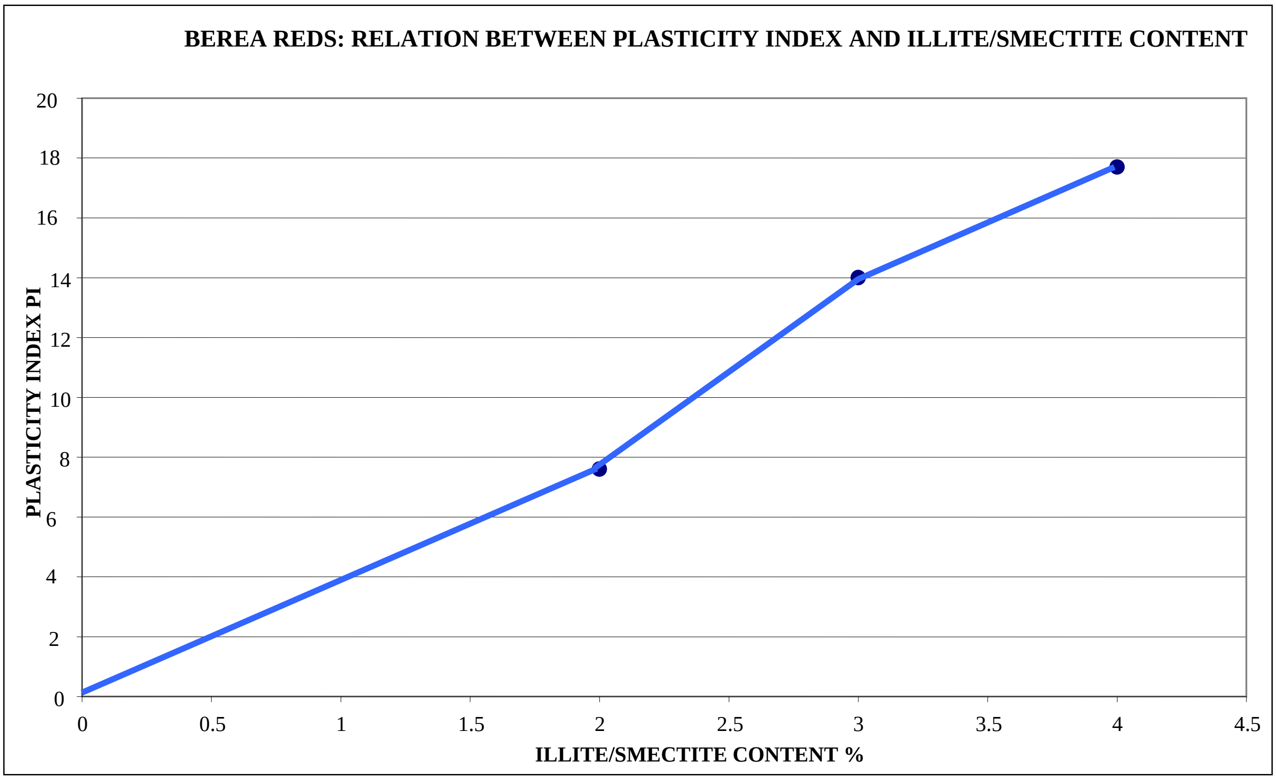

Figure 1 Relationship between P.I and Illite/Smectite

Table 1 and the graph in **Figure 1** indicate:

- The A-2-4(0) materials consist mainly of:
  - 92 – 99% quartz
  - 1 – 2% of Illemenite and Hemetite (Iron oxide) – affects colour
  - 0 – 2% Kaolinite } Affect PI
  - 0 – 2% Illite and Smectite
- The A-6(1) materials consist mainly of:
  - 83 – 87% quartz
  - 2 – 4% of Illemenite and Hemetite (Iron oxide) – affects colour
  - 6 – 9% Kaolinite } Affect PI
  - 3 – 4% Illite and Smectite
- The PI values would appear to be proportional to the percentage Illite/Smectite present in the material
- Koalinite would appear not to play a significant role in influencing the PI of the material as can be seen from the X-ray Diffraction results of samples A and B where there is no Illite/Smectite present but a fair amount of Kaolinite (3%).

2.4 Modification of the "Berea Reds" with coarser material

The addition of < 9,5mm crushed stone aggregate was purely done to establish the trend using a uniform material and therefore show its effect in improving/increasing the Grading Modulus (GM) The < 9,5mm aggregate is a very small aggregate and the effect on the GM is relatively low as is illustrated by the graph in **Figure 2**, however, an addition of 25% of the <9.5 mm aggregate results in a significant increase (60%) in CBR value **(Figure 3).**

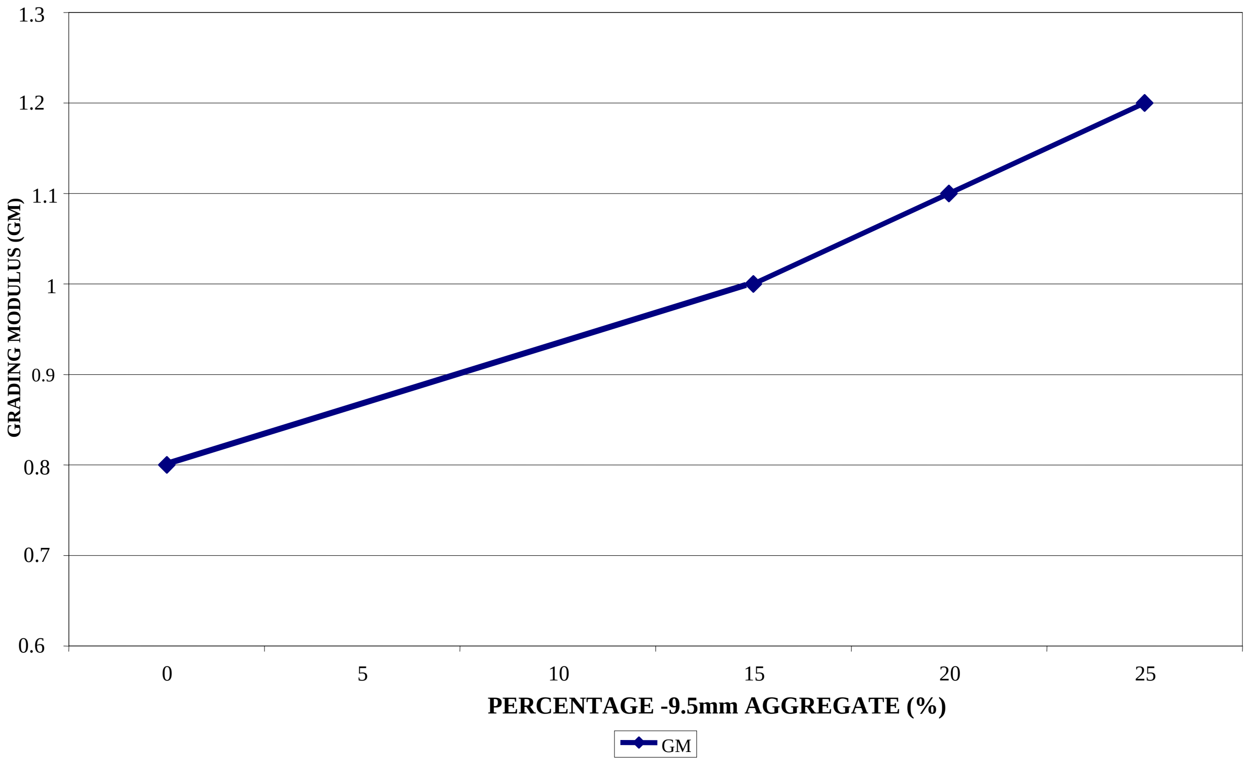

Figure 2 Effect of <9,5mm aggregate on Grading Modulus

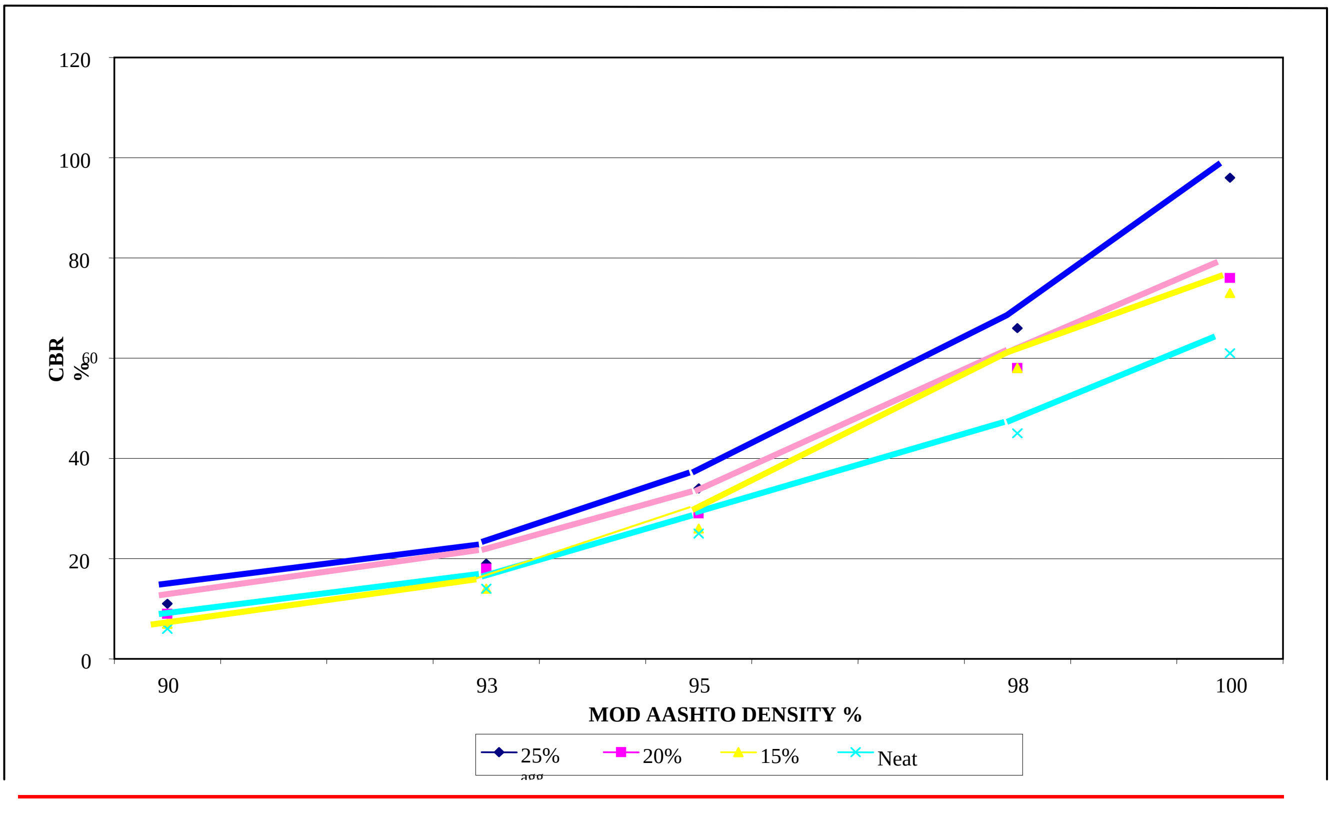

Figure 3 Effect on CBR of various percentages of aggregate at different mod AASHTO compaction levels

The two samples from Mozambique[6] (Samples A and B in **Table 1**) where coarse natural gravel was added are good examples of how the GM and CBR of a fine material can be improved.

Normally suitable natural gravels are scarce in the “Berea Red” locations. Consideration can however be given to importing the required percentage of coarse aggregate from the nearest crusher if natural gravel is not available.

2.5 Emulsion treatment of the “Berea Red” material

The CBR and UCS standard tests[5] have proved to be not totally satisfactory for determining the quality of the material to be used in base and sub-base construction when using emulsion treated material, mainly because the method of curing the sample precludes the breaking of the emulsion. The tests can be used but then the curing procedure has to be modified – even then the tests do not reflect the true value of the emulsion treated material as observed in the field by the author who has successfully designed and specified emulsion treated bases over a period of more than 40 years.

2.5.1 Emulsion treated A-2-4(0) material without modification with coarser material

Table 2 below reflects the change in CBR values to three of the typical composite A-2-4(0) material samples (C1, C2 and C6) when treated with an anionic stable grade emulsion.

Samples C1, C2 and C6 were specifically chosen to demonstrate the following:

- The addition of emulsion to C1, like the clay fraction in C2 acts as a "lubricant" resulting in same order CBR values e.g. C1 (treated with emulsion) has a CBR of 70 while C2 (neat) has a CBR of 80 at 100% Mod. AASHTO.
- Materials with PI values > 6 should be treated with lime before adding bthe emulsion. Note that the CBR of C2 only increased from 80 to 96 with the addition of 1½ % emulsion.
- By adding double the amount of emulsion and 50% more cement (C6 compared to C1) similar results were obtained for similar materials (both obtained treated CBR values of 70 from neat values of 42 and 32 respectively.

Table 2 Emulsion treatment of samples: CBR results

Sample No.	**C1**		**C2**		**C6**	
Classification	A-2-4(0)		A-2-4(0)		A-2-4(0)	
Plasticity Index	N.P.		7.6.		N.P	
CBR results						
% Mod AASHTO compaction	**Neat**	**1% Anionic stable grade emulsion with 1% cement**	**Neat**	**1½ % Anionic stable grade emulsion with 1% cement**	**Neat**	**2% Anionic stable grade emulsion with 1½ % cement**
93	25	40	25	30	17	30
95	28	50	38	45	20	40
98	38	60	60	70	39	58
100	42	70	80	96	32	70

The CBR values that could be obtained in the field utilising the above materials treated with emulsion are considered perfectly adequate for base and subbase for low volume traffic (i.e. low percentages of truck traffic ≤ 5%).

2.5.2 Emulsion treated A-2-4(0) material with modification with coarser material

The line titled "Neat" in **Figure 4** illustrates how the A-2-4(0) material increases in density when adding a small percentage of < 9.5mm crushed stone (coarse) material to the sample e.g. increasing from 1987 kg/m^3 to 2073 kg/m^3 by adding 20% of coarse material (an increase of 4,3%).

By adding a small percentage of emulsion (2%) to the sample the line titled "Neat" moves up to the line "Em treated" resulting in the density of the A-2-4(0) material increasing to 2087 kg/m^3 (at 20% coarse aggregate i.e. an increase of 5%).

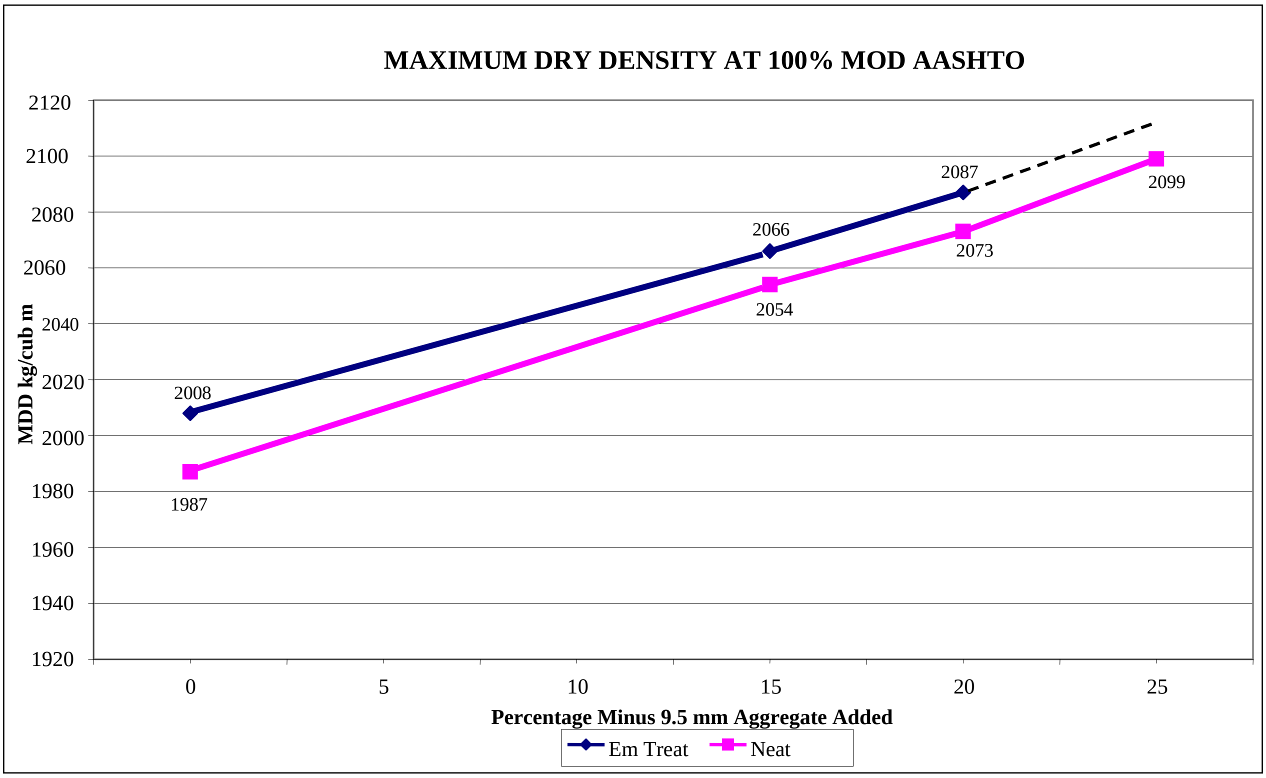

Figure 4 Effect of addition of various percentages of < 9.5mm aggregate and 2% emulsion on density of A-2-4(0) material

Figure 5 illustrates the effect of adding 20% <9.5mm aggregate with 2% emulsion. The CBR value increased by 93% while the density increased by 5%, showing a significant effect on CBR

NOTE: Increase in density is a function of the initial air voids content

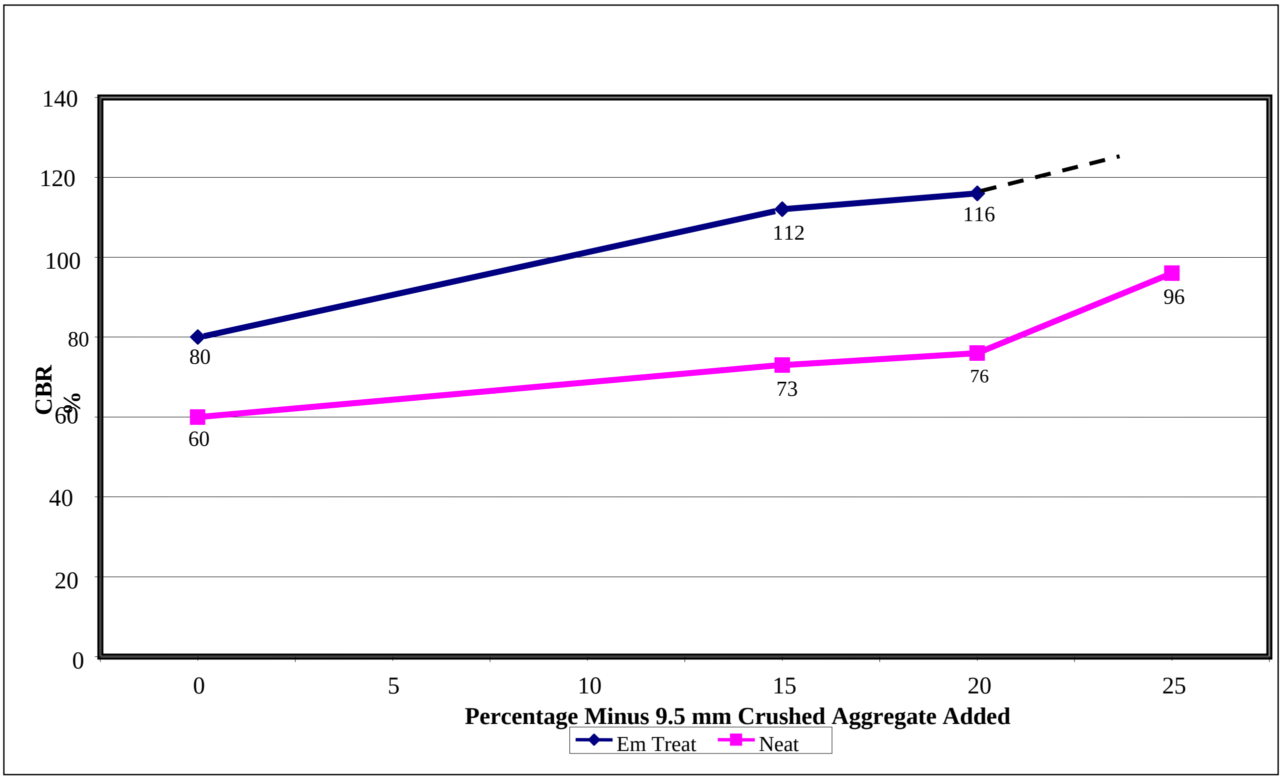

Figure 5 Effect of addition of various percentages of -9.5mm aggregate and 2% emulsion on strength (CBR) of A-2-4(0) material

The addition of emulsion tends to facilitate achieving higher compactive densities resulting in higher CBR strengths.

If the CBR values are considered too low for the present volumes of traffic they can be readily increased by adding a small percentage of crushed stone prior to treatment with the emulsion.

2.6 Treatment of the “Berea Reds” with lime

Two of the typical composite A-6(1) samples (C3 and C4) were treated with lime and the effect of this on the CBR value of the material is reflected in **Table 3**.

The samples C3 and C4 were selected for treatment with lime as both were “high” PI materials (14 and 18 respectively). These were the highest values of the Berea Red material found at the time of the soil survey.

Table 3 Lime treatment of samples: CBR results

Sample No.	C3		C4	
Classification	A-6(1)		A-6(1)	
Plasticity Index	Before stabilization: 14.		Before stabilization: 18.	
	After stabilization; 8		After stabilization; 8	
CBR results				
% Mod AASHTO compaction	**Neat**	**3% lime**	**Neat**	**4% lime**
93	17	60	11	60
95	22	75	14	75
98	28	110	18	90
100	30	133	20	100

The resultant Plastic Index (PI) values of 8 after stabilisation appeared suspect, so the lime was check tested by the South African Bureau of Standards (SABS) and found to be sub-standard. According to the SABS tests there was only 45% CaO available (SANS 824 requires 60%).

A further UCF test was done on a A-6(2) material, from the same source, with a PI value of 12 with a different (up to standard) lime and the resulting PI was zero after stabilisation.

At the time when it was established, the CBR standard of 150 in the field for lime stabilised gravels was based on a safety factor of approximately 2, i.e. approximately twice the CBR of 80 set for unstabilised material. It is the authors', considered opinion that this is a very conservative approach especially if the other factors affecting performance are well within limits e.g. PI = NP, LS = 0 and CBR swells = 0.

2.7 Historical use and performance of Berea Red material stabilised with lime

As part of the investigation[4] an effort was made to locate and assess the performance of roads/streets built with Berea Red sands. An approach was made to A A Louden, a consulting engineer with many years experience in the area, to arrange for cores to be taken on several roads, built with Berea Red sands, where he was involved and briefly report on the performance of the material.

His firm have successfully used Berea Red materials stabilised with lime on several projects, both for base and subbase layers.

His report[7]concludes that, after 30 years, the Berea Red bases, covered in the report are still intact, although deterioration has occurred in places under heavy vehicles. According to Mr. Louden, "*the fact that these bases have given reasonable service over a long period, with maintenance limited to a thin premix overlay, reseal and a tolerable amount of patching, is in my opinion, more than sufficient justification for the future use of this type of construction on lightly trafficked roads".*

From the photographs of the cores **(Appendix B)** it is quite clear that the lime stabilised material is still in surprisingly good condition, after 30 – 40 years use.

3. COMMENTS ON TREATING THE "BEREA RED" MATERIAL WITH EMULSION

The following comments on the advantages of emulsion treatment and recommendations regarding the curing of emulsion treated samples are based on the author's experience of the treatment of materials with bitumen emulsions, over a period of some 40 years.

3.1 Advantages of treating "Berea Red" materials with emulsion

This experience has shown that there are several advantages of treating the material with emulsion viz:

- There are no stabilisation cracks as would be the case with cement and to a lesser degree with lime, resulting in little if any water entering the system via the cracks – no possibility of pumping and secondary cracking;
- The system is more impervious than unstabilised material;
- The pavement is relatively more flexible than is the case with cement stabilised layers, which tend to be rigid and prone to cracking;
- No priming of the base surface is required – no delays due to curing of prime and cost savings;
- No special curing of the ETB is required;
- It is inherently a very stable material, and
- It is well suited for construction by labour and light plant

3.2 Curing of CBR and UCS samples before testing of emulsion treated materials

As previously stated the "standard methods" [5] of curing the CBR and UCS samples is not appropriate as the true strengths of the sample can only be determined once the emulsion has broken.

To overcome this it is recommended that the samples be placed in an oven at 60^{o} C and the loss of moisture controlled until the residual moisture is less than 30% of the original moisture in the sample.

Even this method does not reflect the true strength generated when the emulsion breaks completely as DCP tests have indicated an increase in 'strength' developing over a period of time[8].

4. CONCLUSIONS

The various tests and modification/treatment/stabilisation approaches described in this paper are essentially preliminary results illustrating what can be achieved with the various classes of "Berea Reds".

The paper also concludes that:

- The low Grading Modulus (GM) of the Berea Reds is no justification for disqualifying the material for use in the upper layers of the pavement. The cores discussed under section 2.7 are examples of bases constructed with materials with low GM values that have performed well;

- The "Berea Reds" are no more variable than any other natural gravel source material, and

- Apart from the inherent strength of the material it is also an extremely stable material, being in most cases non plastic, with no or very little CBR swell with even the A-6( ) materials having insignificant swell values.

What has probably led to some confusion, however, is that all the "sandy material" along the east coast has been referred to as "Berea Reds" irrespective of the colour of the sand which can vary from light yellow to orange and light to dark brown or dark red

5. GENERAL COMMENT

In summary it is the opinion of the authors that the elimination of the Berea Red sands as a suitable material for use in the upper layers of a road foundation, basically, because the material generally has a Grading Modulus (GM) of less than 1 and is alleged to be too variable, is unfounded. Berea Red sands can be modified/stabilised/physically changed to make them suitable for use both as a subbase and base layer for road works.

Application of the design method and classification advocated in TRH 4 "Structural design of flexible pavements for interurban and rural roads" will unfortunately still classify the Berea Red sands as unsuitable for use as subbase and base material.

A method for designing roads making use of the CBR design curves the so called "National Roads" design is attached as **Appendix A**.

This approach which, will accommodate the use of the Berea Red Sands in the construction of subbase and base construction, can be used as a guide for designing the foundations of roads using "Berea Reds" for these layers.

6. ACKNOWLEDMENTS

The authors would like to acknowledge:

- The late Piet Botha for his role in the testing and check testing of the material, and

- Allan Louden for his input regarding the information relating to the performance and life of the lime treated Berea Red material.

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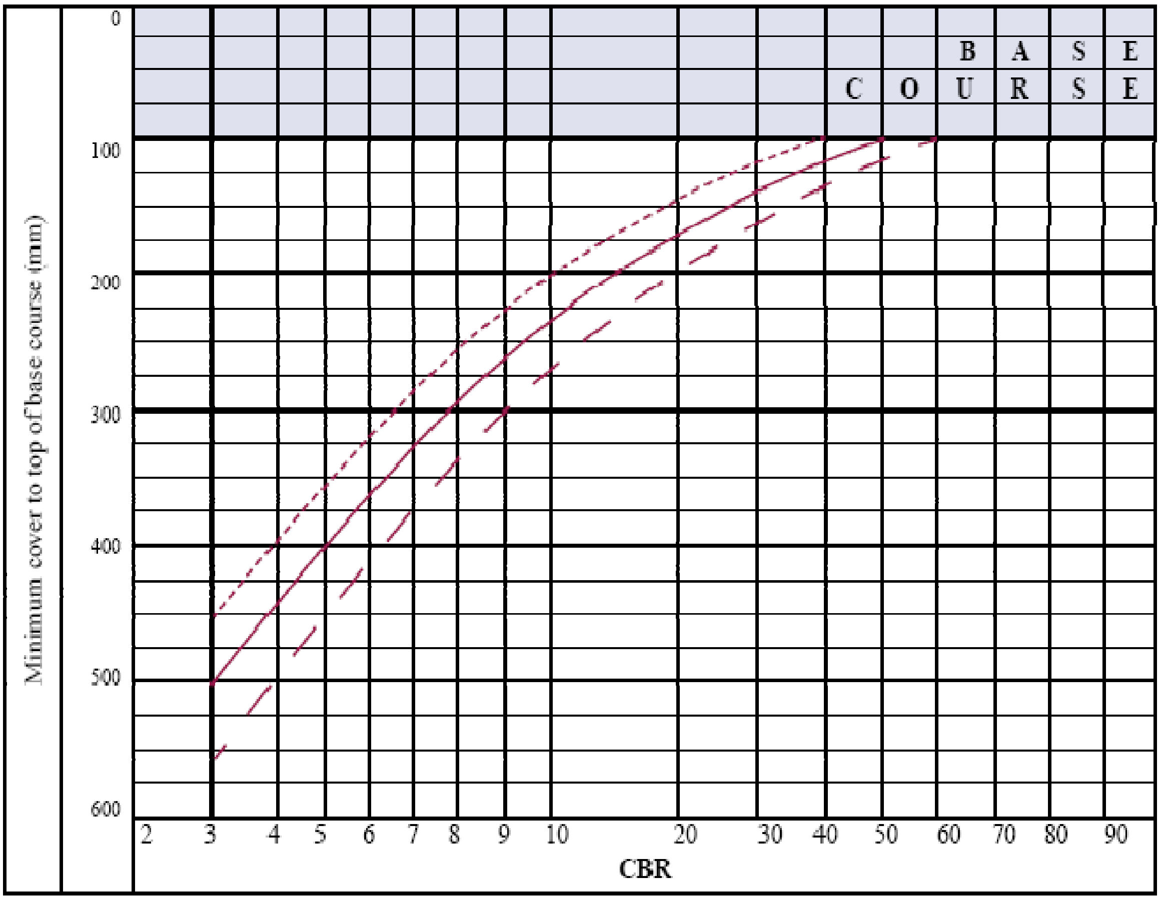
APPENDIX A

METHOD FOR DESIGNING ROADS USING CBR DESIGN CURVES

The graphs have been included as a guide for assessing the use of Berea Reds for road construction purposes.



------- 7000 lb (+30 kN) wheel load ——— 9 000lb (+ 40 kN wheel load)

— — — — 12 000 lb (+ 60 kN wheel load)

<u>Requirements on National Roads for Base course, Subbase and Subgrade</u>

1. Minimum soaked CBR of material as it is in place to be shown on above chart, and the density and moulding moisture specified shall be such as to conform to the design CBR
2. Minimum soaked CBR of top 6" (150mm) of modified AASHO compaction and optimum moisture content to be 80% and minimum soaked CBR of top 6" (150mm) moulded to in-place field density to be 50% (Increased to 80% in 1950)
3. Maximum CBR swell of base course material at modified AASHO compaction and optimum moisture content: 0.5%
4. Maximum PI of base course material: 6 (Reduced from 8 to 6 in 1950)

CBR Curves for various wheel loads: National Road design

The 7 000lb (+ 30kN) wheel load design curve was used for the design of all National roads built at the time (+ 1949) including the link between Belfast and Middelburg which consisted of two 100mm layers of laterite/ferricrete surfaced with a double seal. This design lasted some 40 years.

These curves can still be used as a guide for designing the foundations of roads using “Berea Reds” for base and sub-base layers.

The 7 000lb ($\pm$ 30kN) wheel load design curve is proposed for low volume roads (streets) i.e. less than 1 000 vehicles per day with $\leq$ 5% heavy vehicles.

The 9 000lb ($\pm$ 40kN) wheel load design curve is proposed for traffic up to 3 000 vehicles per day with 5% heavy vehicles.

As mentioned earlier, if the intensity of traffic increases different quality/thickness of surfacing could be applied depending on the traffic intensity as a stage construction process.

APPENDIX B

PHOTOGRAPHIC EXAMPLES OF RODS CONSTRUCTED WITH BEREA RED SANDS BASED ON THE CBR DESIGN CURVES

Photographs 1 to 4 below are examples of cores taken from the road from the N3 intersection to Charters Creek built 30 to 40 years ago using Berea Red sands, stabilized with lime and surfaced with a thin double seal

Photo 1 Core 1 on Charters Creek Road

Photo 2 Core 2 on Charters Creek Road (0 – 120mm)

(It is quite clear that the integrity of the lime stabilized material is still sound - no deterioration into sand or clay)

Photo 3 Core 2 on Charters Creek Road (120 – 175mm)

Photo 4 Core 2 on Charters Creek Road: Surfacing

(The thin surfacing has performed remarkably well over a period of some 30 to 40 years under fairly light traffic, but with a high percentage of heavy timber and cane trucks)