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ELASTIC-PLASTIC PERFORMANCE OF CALCRETE STABILISED UNBOUND MATERIAL FOR OPTIMISED USE IN PAVEMENT LAYERS IN NORTHERN NAMIBIA

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Abstract: To understand the performance limits and to provide reliable prediction performance of different calcrete and sand mixes, the Elastic-plastic performance model of calcrete stabilised unbound material for optimize use in pavement layers in northern Namibia was investigated through the use of short-term monotonic triaxial tests conducted in the laboratory. General aspects of the behaviour of unbound granular materials were investigated , and results obtained through the use pavement software revealed that pavement performances in Northern Namibia could be not only be improved by at least three folds, but will also significantly reduce long term construction costs. The Rubicon Tool box was used to also describe permanent-deformation behavior of such pavement.

Keywords: *Elastic, Plastic, Performance, Calcrete, Triaxial & Material*

1.0 Introduction

This research demonstrates the application of the Monotonic Triaxial test. Based on triaxial tests conducted in the laboratory, results obtained were being modeled in the Rubicon toolbox computer software i.e. a static loading based model, to characterize the behaviour of calcrete, sand and a mixture of the two materials as base and sub base materials. to explain the different responses of different blending ratios of materials under confined pressure, an existing approach that is based on monotonic energy was proposed.

The applied energy approach illustrated that there are responses during, triaxial tests, namely, elastic and plastic responses, which are dependent on the loading levels and type of tested materials which in this case, refers to the different mix designs. It was also observed that the transition from elastic to plastic response involved gradual microstructural adjustments of the tested materials to accommodate the applied loading. This gradual transition explains the difficulties in identifying some material responses within the Monotonic Triaxial test based only on the permanent strain rate criteria.

Based on the results of this study, a mechanistic-based design procedure to incorporate various pedogenic materials into pavement bases was recommended. (Siripun.K, 2011)

2.0 Material Type

The selection of materials for a road pavement design is generally based on a combination of availability of suitable materials, environmental considerations, method of construction, economics and long term field and laboratory experiences. These factors need to be evaluated during the design in consideration of the Life Cycle Strategy (LCS), in order to select the materials that best suit the conditions. (TRH 4,1996)).With the basic understanding of how a pavement should behave under wheel loading, a simulated computerized programme (Rubicon toolbox), was used for the layered elastic evaluation for standard axle based on the unblended available material to be used.

3.0 Research Methodology

- Representative samples of calcrete and local sand were sampled randomly along the route.
- Monotonic triaxial testing was conducted.
- The MOD, CBR, Plasticity Index and grading tests were conducted.

Different steps in the mix design were carried out as follows:

Step 1
- 100% of a representative calcrete sample to be tested naturally
- 100% of a representative sand sample to be tested naturally
- Results analyzed and recorded.

Step 2
- 50 /50 mix of the sample to be tested as above
- Results analyzed and compared with the ones on step 1

Step 3
- 75% Calcrete and 25% sand mixed and tested
- Results analyzed and compared with the ones on step 1/2

Step 4
- 85% Calcrete and 15% sand mixed and tested
- Results analyzed and compared with the ones on step 1/2/3

With the above tests completed and evaluated, the best performing blended mix was then be Modeled in Rubicon (tool box), to determine the suitable Equivalent Standard Axial Load for the pavement.

4.0 Scope of Works

This paper addresses the Elastic-plastic performance of calcrete stabilised unbound material for optimised use in pavement layers in Northern Namibia. It was aimed at establishing a reference relationship between sand mixed with calcrete and how do these materials develop other important properties such as tensile strength, relaxation and elastic moduli. Also the model predicts the performance of pavement structures. The influences of the angle of friction, cohesion and lateral stress which affect are the performance and durability of the pavement were considered in this research.

5.0 Material Properties and Results of Laboratory Tests

Table 1 shows the material description, which were be crushed stone G3 for base course or subbase. The material reference column represents the mix proportions of different materials, such as A -85/15 which is composed of 85% G3+15% sand. The MOD AASHTO,Optimum Moisture Content (OMC), target densities and results obtained after carrying out the tests were also shown including the Target Density (i.e. the maximum density the material should reach).

Materials tested for monotonic triaxial testing are described as shown in the table.

Table 1: Volumetric properties and description of each material reference

Material Description	Reference	Composition	**Mod AASHTO (kg/m³)**	**OMC**	**Target Density (%)**
Crushed Stone (Crushed G3) for the Base Course	A-100	100% Calcrete	2247	6.2	98
	A-50/50	50%G3+50% Sand	2204	6.4	98
	A-75/25	75%G3+25% Sand	2298	5.7	98
	A-85/15	85% G3+15% Sand	2284	5.2	98
Crushed Stone for the sub base Course	B-100	100% Crushed Stone	2286	6.5	95
Calcrete (*BP18*) For the sub base Course	C-100	50% Calcrete +50% Sand	1764	16.1	95
	C-50/50	50% Calcrete +50% Sand	1931	12.6	95
	C-75/25	75% Calcrete +25% Sand	1836	14.5	95
	C85/15	85% Calcrete +15% Sand	1804	15.8	95

Calcrete (*BP 17A*) For the Selected Subgrade	D-100	100% Crash Stone	1694	12.7	93
	D-50/50	50% Calcrete +50% Sand	1906	11.8	93
	D-75/25	75% Calcrete +25% Sand	1832	13.5	93
	D-85/15	85% Calcrete +15% Sand	1786	13.5	93
Sand (*BP18A*) For the Roadbed & Fill	E-100	100% Calcrete	1897	5.8	100

5.1 *Summary of Monotonic test results*

To determine the moisture content, after the triaxial test, each specimen was crushed and a representative sample of the material was taken from the centre of the specimen. Results of moisture content obtained for all test samples are as summarized in Table 2.

Table 2: Summary of monotonic test results, shear properties and MC after the test

Materials Reference		Confinement stress σ_3(kPa)	Maximum vertical load (kN)	Cohesion C,(kPa)	Internal Angle of Friction φ ,(°)	Moisture Content (%)
A-100	A-100-1	100	14.514	*1)* *2)* 163	*3)* *4)* 46.44	5.85
	A-100-2	100	14.59			5.50
	A-100-3	200	17.928			5.76
	A-100-4	50	11.234			5.38
	A-100-5	50	8.829			5.48
A/85/15	A-85/15-1	50	6.2391	*5)* *6)* 225	*7)* *8)* 14.53	5.13
	A-85/15-2	200	7.11028			4.83
	A-85/15-3	100	6.5413			4.99
	A-85/15-4	50	5.9723			5.26
A-75/25	A-75/25-1	100	5.2267	*9)* *10)* 133	*11)* *12)* 19.88	5.06
	A-75/25-2	200	5.6034			5.90
	A-75/25-3	50	3.9750			5.16
	A-75/25-4	100	5.1168			5.14
	A-75/25-5	50	4.0848			5.31
	A-75/25-6	200	5.7996			5.94
A50/50	A-50/50-1	50	6.8434	*13)* *14)* 121	*17)* *18)* 48.64	5.57
	A-50/50-2	50	9.951			5.80
	A-50/50-4	200	17.426			5.48

	A-50/50-1	50	6.8434	*15)* *16)*	*19)* *20)*	5.57
B-100	B-100-1	50	5.43	*21)* 79	*22)* 43.75	5.89
	B-100-2	100	7.32			6.23
	B-100-3	200	12.92			6.01
	B-100-4	50	6.96			6.47
C-100	C-100-1	50	6.2940	*23)* 281	*24)* 6.32 *25)*	15.58
	C-100-2	100	6.2940			15.23
	C-100-3	200	6.7100			15.09
	C-100-4	100	6.5570			15.39
	C-100-5	50	6.3843			15.61
C-50/50	C-50/50-1	50	5.4857	*26)* 151	*27)* 25.42	11.65
	C-50/50-2	50	5.5249			11.98
	C-50/50-3	100	6.3411			11.82
	C-50/50-4	200	7.7616			11.27
C-75/25	C-75/25-1	50	4.2536	*28)* 140	*29)* 24.00	14.17
	C-75/25-2	100	6.1920			14.06
	C-75/25-3	50	5.3209			14.01
	C-75/25-4	200	6.8434			13.37
C-85/15	C-85/15-1	50	5.528	*30)* *31)* 197	*32)* *33)* 15.37	14.85
	C-85/15-2	100	6.023			15.01
	C-85/15-3	200	6.5766			15.29
	C-85/15-4	100	5.9684			15.18
	C-85/15-5	200	6.5216			15.03
D-100	D-100-1	100	5.2934	*34)* *35)* 125	*36)* *37)* 23.68	14.05
	D-100-2	50	3.7081			13.77
	D-100-3	200	5.8546			13.55
	D-100-4	50	4.7833			14.01
	D-100-5	100	5.7486			14.15
	D-100-6	200	6.9062			14.92
D-50/50 *38)* D-50/50	D-50/50-1	50	9.9237	*39)* *40)* 346	*41)* *42)* 19.59	11.94
	D-50/50-2	50	10.2494			12.29
	D-50/50-3	100	10.8223			12.36
	D-50/50-4	100	11.4227			12.58
	D-50/50-5	200	11.5993			12.36
D-75/25	D-75/25-1	50	5.2817	*43)* *44)* 85	*45)* *46)* 41.68	13.93
	D-75/25-2	50	5.3444			14.70
	D-75/25-3	100	10.0062			13.91
	D-75/25-4	200	11.2658			14.96
D-85/15	D-85/15-1	50	6.4549	*47)*	*48)*	14.67
	D-85/15-2	50	5.3052	*49)* *50)* 169	*51)* *52)* 26.33	14.21
	D-85/15-3	100	7.6596			13.72
	D-85/15-4	100	7.4556			14.39
	D-85/15-5	200	8.2717			14.34

results between ***A-100 to A50/50 mix ratios*** of can be graphically summarized and explained as shown in Fig. 1 below.

5.2 Graphic representation of results for A-100 to A50/50 mix ratios

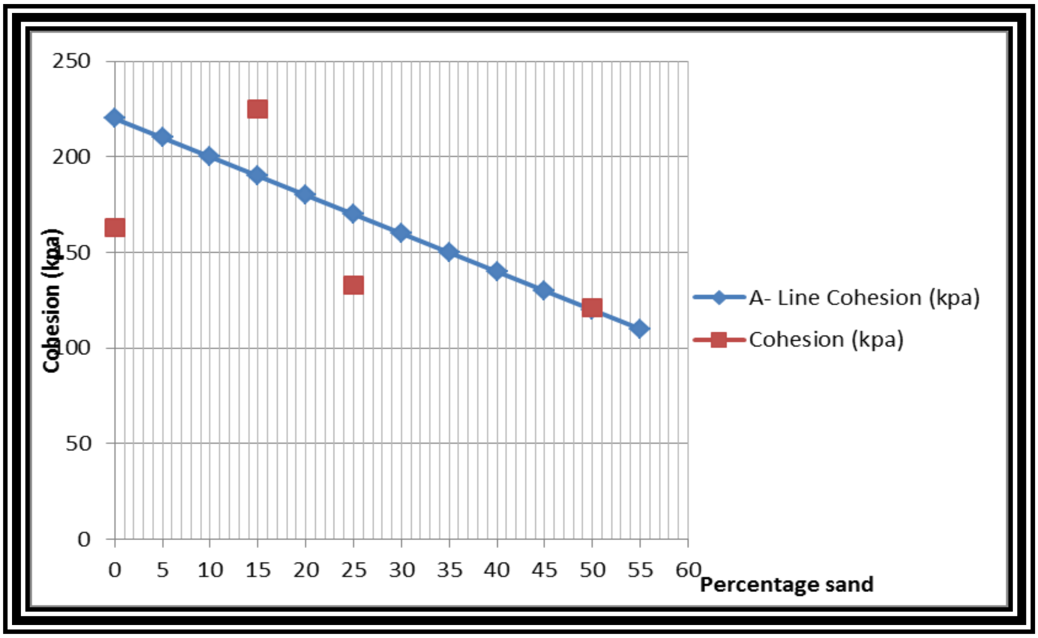

Fig.1: Cohesion vs. sand for “A” mix ratios

The relationship between cohesion and percentage of sand is presented in Fig. 1. The A-line of cohesion shows the theoretical relationship obtained by taking the average cohesion of the specific mix group. The mix ratio for A85/15 shows a cohesion of 225 kpa, suggesting that it is out of range . The other mix ratios of A-100, A75/25 and A50/50 respectively fall below the theoretical average line. According to the South African Mechanistic Design Method, the suggested ranges of elastic moduli for granular materials are suitable for base course and are classified as a G5.

Fig. 2 below gives the performances envelop developed in this study based on the monotonic triaxial test results, and related literature shown in tables found in R.B Peck (1974)‘s research. The performance envelope clearly indicates the ranges from poor to good material cohesion verses the angle of friction. In some cases if the angle is high and the cohesion is less, then the material falls in the poor category and likewise for the rests of the readings.

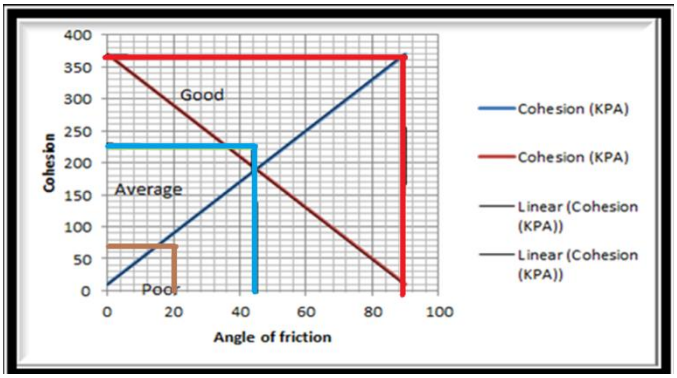

Fig. 2: Summary Envelope for Cohesion vs. Angle of Friction

Based on research done by R.B. Peck (1974 that defines criteria for a good, average and a poor material that was applied in this research to classify the performance of the materials tested, a tested sample having an angle of friction of 20 degrees and cohesion of 50Mpa, means the sample is poor, that for cohesion of 150 Mpa, means average, and that for cohesion above 250Mpa means a good sample.

With the understanding of the Rubicon application, the first analysis illustrated a conventional pavement, G3 base, G5 sub base and G5 selected layer. The first and second pavement analysis with pre-determined cohesion and internal angle of friction values as prescribed by Rubicon indicated the sub base as the critical layer with an expected life of 2.6 million standard axles. Thus in accordance with the TRH4 catalogue a pavement with such characteristics falls under the TRH4:ES3, 1-3 Mill E80 pavement class, as shown in Fig. 3: TRH 4 Pavement Catalogue below.

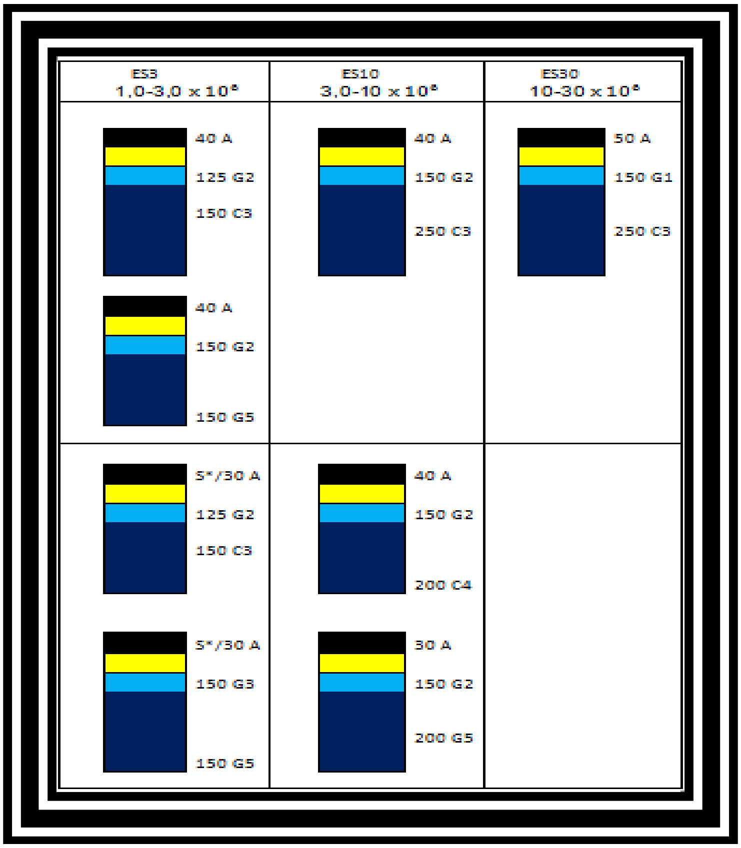

Fig.3: TRH 4 Pavement Catalogue

After several simulations, the rest of the pavement modules were based on actual cohesion and internal angle of friction as determined through the tri-axle testing. These results proved that the mechanically modified materials to be used on MR122 pavement perform very well in terms of expected life, with the critical layer being the in-situ sub grade material and not the subbase layer as in the earlier cases. These pavements effectively performed better than the conventional pavements. Thus in accordance with the TRH4 specification catalogue, the mechanically modified materials improved exponentially from being a ES3 type of pavement to either a ES10 of "lower" ES30 pavement classification.

5.3 Analysis of results – Summary

Despite the different mixing ratios for the material, the MOD AASHTO values were higher than the target compaction This is very much acceptable for both Base and Subbase layers as stipulated in the COLTO specifications i.e. 95% and 98% COLTO for subbase and base course layers respectively between a MOD values range of 96.1% and 101.8%. Sine moisture content played a significant role during the mixing process, the moisture content quantities ranged between a high values of 16.1% for D/75/25%, mix ratio and low values of 5.05% for A/85/15 mix ratio. Furthermore, the MOD between the two mixes was very small, having 98.5% for the D/75/25 mix and 99.3% for the A/85/15 mix.

6.0 Discussion of Results

The mix design A/85/15 that resulted in cohesion of 225 KN/m2 and an angle of friction of 14.5 proved to be the most acceptable and most practical mix for base course material, compared to the rest of the samples. This shows that the material is more elastic in characteristics. It has a shear safety factor of 1.5, less than that of C100, which had a shear safety factor of 9.56 that was used for selected subgrade layer. For the A85/15 mix design, it was 43% stiffer compared to C100. Thus the Stiffness of the mix A/85/15, was 350 MPa, while for C100 produced a Stiffness of 150MPa. D50/50 mix resulted in the highest cohesion of 346 KN/m2 and an angle of 19.9°. However, the stiffness compared to A85/15 and C100 was 100MPa. This meant that both C100 and D50/50 could not meet the minimum requirements for base course material, as their stiffness values were lower than that of A85/15. Hence it can be useful for subbase layers.

7.0 Conclusion

Results of the triaxial tests provided varying values in terms of shear parameters. Clear differences in the shear parameters were evident for the different mix, hence provided guidance for the selection of materials that would give preferential performance. Some unusual results were also apparent with extremely low values for angle of internal friction.

It should however be noted that laboratory test results were obtained from samples tested under ideal conditions that might not be the case in the field. Hence long term monitoring in the field should be encouraged since results obtained thereafter reflect real life simulations.

Also, the use of the International Roughness Index (IRI) for a specified period as well as the use of Falling Weight Deflector meter (FWD), Dynamic Cone Penetrometer test (DCP) and the like should be recommended.The Rubicon Toolbox analysis with predetermined ideal cohesion and internal angle of friction values as inputs proof that the current pavement design with mechanically modified materials performs better than the unblended material. The expected pavement life was also improved.

The expected life in terms of standard axle repetitions is in excess of 10 million E80s, when these ideal laboratory test results were used. Taking all construction tolerances and material variability into account, i.e. the adverse weather conditions, the quality and the quantity of the mixing water, workmanship, and the like, it can still be said, that the mechanically modified materials with the correct mixing ratios, can be recommended for used in the MR122 pavement layers.

These different mixes would be of good performance and satisfactory quality, keeping in mind that before the mechanical mixing took central stage; the material had performed well in the conventional pavement models, that had an expected life of more than 2.6 million E80's. Hence in accordance with the THR14 specification, classed the pavement between 1 and 3 million E80's (ES3), which is recommendable for a low volume roads

8.0 Recommendations

Based on this laboratory investigation, it has been shown that Blended Calcrete/sand as sub layers has a higher combined cohesion for pavement structure material and can be used for various civil constructions. The ultimate indicator of a material's quality is its capability to perform under actual service conditions. However, it can be recommended that further research have to be done to focus on correlating laboratory test results to that obtained in the field for blended materials.

Moreover to further define the behaviour of this material, the following recommendations can be made:

- Further research is necessary to fully quantify parameters that affect the resilient modulus of the pavement. The length of testing should be extended to get more data leading to long-term behaviour.

- A further research of Cost Benefit Analysis has to be conducted to ensure that the road users' needs are met.

- The trial section's performance has to be monitored so that defects and their types are dictated earlier.

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