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Low Cost Roads Stabilized by ECOLOPAVI

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Abstract: This study presents the effect of ECOLOPAVI stabilizer on Low Cost Roads (LCR). This study found that a mix of 2% cement and 5% ECOLOPAVI can improve the bearing capacity (CBR) of clayey soil with CBR = 3% up to 49%; similar result can be get by adding 6% to 7% of cement or lime in conventional practices; that means the combination of ECOLOPAVI with cement or lime can be used to reduce the construction cost of roads. This product is presented as an alternative to other conventional stabilizer in use (cement or lime). In this research, ELSYM 5 program is employed to evaluate and compare two pavement structures with natural subgrade soil and with stabilized subgrade. The pavement response show that it is strongly dependent on subgrade layer elastic or resilient modulus; as the depths increase, the stresses, displacement and strains decreased. The results of two pavements (one with subgrade CBR $\geq$ 3% and another with subgrade CBR $\geq$ 12%), show that the structure with subgrade CBR $\geq$ 12% gave low stress, displacement and strains than that with CBR $\geq$ 3%.

Key words: Low cost roads, ECOLOPAVI stabilizer, structural capacity

INTRODUCTION

The improvement of road infrastructure is one of the key elements in the development process. LCR are particularly different from other kinds, with a very low traffic volume, usually less than 200 AADT (Annual Average Daily Traffic); usually are located in areas with poor quality materials for construction (Zheng *et al*., 2005). This study describes the research conducted in Geotechnique Laboratory based at CONCRESONDA COMPANY, Brazil on ECOLOPAVI stabilizer with an objective to study LCR in Mozambique. This study was conducted due to the following reasons: (a) to study the possibility of use of this stabilizer in chemically improving the structural capacity of LCR in Mozambique; (b) to study LCR that represent the main road system and guarantee connection between rural areas, flow of the agricultural goods and services in Mozambique (David, 2002); (c) to investigate the effect of ECOLOPAVI on structural improvement of subgrades, subbases and bases bearing capacity of roads; and (d) to define a Laboratory mixture design to assure that all properties necessary to meet these structural demands are achieved as part of a mechanistic design/analysis approach. In resume, this study aims to investigate the effect of the combination of ECOLOPAVI with lime or cement in modification of bearing capacity of pavement structure composed of *in situ* soils.

Generally, ECOLOPAVI stabilizer is a liquid used in combination with cement or lime at different volume proportion; this stabilizer is under research by IDESA (Instituto de Desenvolvimento e Educação Social da Amazonia), Brazil; this product is manufactured by the company HICPM (Homi Industria e Comércio de Produtos Químicos, Ltda) based in S. Paulo, under License of IDESA, located in Manus, Brazil. Many other stabilization methods are presented by Yoder and Witczack (1975), Oglesby and Hicks (1982), Little (1999), Little *et al.* (2002), Jirathanathaworn *et al.* (2006) and INDOT (2002). The ECOLOPAVI technology and physic-chemical properties are discussed by Roessler (2006). The effect of ECOLOPAVI in structural capacity is presented herein.

MATERIALS AND METHODS

Background: The improvement of bearing capacity of LCR requires treatments, generally, classified into two processes (INDOT, 2002), (1) soil modification and (2) soil stabilization. The replacement of the existing weak soil by the transported one from borrows pit normally located far from the road alignment, is high on transportation cost. Many developing countries (Brazil, India, Zimbabwe, South Africa, Madagascar, Mozambique, etc.) are nowadays experimenting the stabilization techniques in order to reduce the construction cost. The stabilization methods include physical processes such as soil densification, blending with granular material and use of reinforcement (Geogrids), undercutting, replacement and chemical stabilization (INDOT, 2002).

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Following the different empirical and mechanistic approach design methods in use by several agencies for pavements design, the selection of soils materials is required. The selection is made by material Laboratory (LAB) testing and then preceded the stabilization with ECOLOPAVI according to pavements design parameters to be determined in LAB.

Material testing: In this study, the soil testing was based on Brazilian norms: (a) NBR-07181 for grading analysis; (b) NBR-07182 for compaction testing; (c) NBR 06459 for determination of Liquid Limit (LL); (d) NBR-07180 for determination of Plasticity Limit (PL); (e) NBR 06508 for determination Plasticity Index (PI); and (f) NBR- 09895 for CBR testing (ABNT, 1984a-d, 1986a, b). Testing were carried out on 4 samples, first sample being natural soil, second sample, natural soil + 2% of cement + 5% of ECOLOPAVI and the fourth sample, natural soil + 2.5% of cement + 5% of ECOLOPAVI as shown in Table 1 (soil grading and mixing). In the calculation of California Bearing Ratio (CBR) the standard pressure ($P_{2.5}$ = 0.7 MPa and P_5 = 1.05 MPa) and measured pressure in LAB (P in MPa) at penetration of (2.5 and 5 mm) were used, respectively. The CBR were calculated by Eq. 1 and 2 (Pedraza, 1970). The results were compared and the biggest value was taken.

$$CBR(\%) = \frac{P}{0.7} * 100 \quad (1)$$

$$CBR(\%) = \frac{P}{1.05} * 100 \quad (2)$$

where,
P = the measured pressure in LAB testing, Mpa.

Applications of ECOLOPAVI: The ECOLOPAVI can be applied in soils that visually resist the action of the commercial vehicles wheels loads during the dry weather, without powdering; it can be used to stabilize the following soils; (a) Sand-clay soils with a high inter-granular attrition, in proportion of 1:1.000 in weight and neutralizing Sulfate of Aluminum, in the proportion of 1:5.000 in weight; and (b) For clay-sand or clay-silt soil, very fine, with little or with no inter-granular attrition is recommended to add the agglomerates of type hydrated lime or cement Portland to rich the high CBR values, in the proportion from 1 to 3% in weight and ECOLOPAVI in the proportion of 1:1500 in weight. If we add in ECOLOPAVI to lime, cement, etc., the resistance increases in direct proportion to the increase of the dosage of the agglomerate. The necessary Laboratory research should be made to define the most appropriate dosages for the stabilization considering the economic aspects (Roessler, 2006).

Data analysis: To analyze the pavement response, this study assumed two pavement structures, each one, of 4 layers system to be under a dual circular loaded area. The load in each wheel is 20 kN and contact pressure of 520 kPa (Theyse *et al.*, 1996). All layers (1, 2, 3 and 4) for each pavement are assumed linear elastic. The materials properties of pavement 1 and pavement 2 are given in Table 2 and 3, respectively. The elastic or resilient modulus of subgrade was calculated by Eq. 3 (Yoder and Witczack, 1975).

Table 1: Grading and soil mixing

Sample No.			1	2	3	4
Lane			Local cut	Local cut	Local cut	Local cut
Depth (m)			-	-	-	-
Color			Yellow	Yellow	Yellow	Yellow
Morphologic classification			Natural clay	Natural clay +2% cement	Natural clay + 2% cement +5% ECOLOPAVI	Natural clay +2.5% cement +5%ECOLOPAVI
Grain size distribution	Sieves					
	Inch	mm	Passing by weight (%)			
	3/8"	9.5	-	-	-	-
	4	4.8	100.00	100.00	100.00	100.00
	10	2.0	99.86	99.86	99.86	99.86
	40	0.42	94.82	94.82	94.82	94.82
	200	0.074	87.51	87.51	87.51	87.51
Physics limits	LL	%	95.00	95.00	95.00	95.00
	PI	%	55.44	55.44	55.44	55.44
Classification HRB/USCS			A-7-6	A-7-6	A-7-6	A-7-6
Group index (%)			20	20	20	20
Real density (g m^{-3})			-	-	-	-
Equivalent of sand (%)			-	-	-	-

LL: Liquid Limit; PI: Plasticity Index; HRB/SUCS: Highway Research Board/Unified Soils Classification System

$$E\ (M_R) = 10.3\ CBR \quad (3)$$

where:
E (M_R) = Elastic or resilient modulus in Mpa;
CBR = California Bearing Ratio from CBR testing.

Simulation by ELSYM 5 program: The simulation was made by ELSYM 5, computer program (Kopperman *et al*., 1986). The input data are: (a) load on each wheel = 20 kN; (b) contact pressure of 520 kPa; (c) wheel spacing (S) = 350 cm; (d) elastic modulus; (e) Poisson's ratio (μ); and (f) the thickness of each layer. The parameters (elastic modulus, Poisson's ratio (μ) and the thickness of each layer) can be taken from Table 2 for pavement 1 with stabilization of subgrade and from Table 3 for pavement 2 without stabilization of subgrade.

Table 2: Material sensitivity of the Pavement 1

Layers	Elastic modulus (MPa)	Coefficient poisson ratio (μ)	Thickness (cm)
Asphalt layer	1000*	0.25	3
ECOLOPAVI+cement stabilized base CBR ≥ 43%	500	0.35	12
Cement stabilized subbase CBR(*) ≥ 20%	206	0.35	10
Reinforced subgrade CBR(*) ≥ 12%	123	0.40	47
Subgrade CBR ≥ 3%	36	0.40	∞

* Assumed

Table 3: Material sensitivity of the Pavement 2

Layers	Elastic modulus (MPa)	Coefficient poisson ratio (μ)	Thickness (cm)
Asphalt layer	1000*	0.25	3
ECOLOPAVI+cement stabilized base CBR ≥ 43%	500	0.35	12
Cement stabilized subbase CBR(*) ≥ 20%	206	0.35	10
Subgrade CBR ≥ 3%	36	0.40	47
Subgrade CBR ≥ 3%	36	0.40	∞

*Assumed, CBR: California Bearing Ratio

RESULTS AND DISCUSSION

CBR performances: Generally, a subgrade's performance depends on its three basic characteristics: (a) Load bearing capacity; (b) Moisture content; and (c) Shrinkage or swelling. The subgrade must be able to support loads transmitted from the pavement structure. The load bearing capacity is often affected by degree of compaction, moisture content and soil type (Yoder and Witczack, 1975; Pedraza, 1970). Good subgrade is that can support a high amount of loading without excessive deformation. Moisture content may affect a number of subgrade properties including load bearing capacity, shrinkage and swelling, it means that excessively wet subgrades will deform excessively under load. Some soils shrink or swell depending on their moisture content.

The CBR performances are shown in Table 4, which indicate that sample 1 (natural soil) recorded a lower pressure than sample 2 (natural soil + 2% of cement); and sample 2 recorded a lower pressure than sample 3 (natural soil + 2% of cement + 5% of ECOLOPAVI). But sample 4 (natural soil + 2.5% of cement + 5% of ECOLOPAVI) shows that if the percentage of cement is higher than 2%, the required pressure decreased. The result of sample 4 was not expected. Thus, further studies on this stabilizer are recommended. The resume of material testing results is given in Table 5. Other details concerning the calculation report are not presented in this study.

Pavement evaluation response: The results generated by ELSYM 5 program (Kopperman *et al*., 1986) are shown in Fig. 1. Pavement responses comparisons between pavement 1 (with stabilized subgrade, CBR ≥ 12%) and pavement 2 (without subgrade stabilization, CBR ≥ 3%). Figure 1a shows that the vertical stresses are very high on the surface layer; the stresses decrease as the depth

Table 4: CBR performances

Sample description	Measured pressure at different penetrations (MPa)									
Penetration (mm)	0.00	0.64	1.27	1.91	2.54	3.81	5.08	7.62	10.16	12.70
1. Natural clay	0.00	0.05	0.10	0.14	0.18	0.26	0.34	0.52	0.65	0.97
2. Natural clay +2% cement	0.00	0.79	1.30	1.72	2.04	2.40	2.54	2.89	3.20	3.53
3. Natural clay +2% cement +5% ECOLOPAVI	0.00	2.08	2.79	3.13	3.47	3.97	4.48	5.17	5.68	6.38
4. Natural clay +2.5% cement +5% ECOLOPAVI	0.00	1.54	2.13	2.63	3.03	3.57	4.27	4.66	4.87	5.36

Table 5: Resume of Results of Soil Testing

Sample No.		1	2	3	4
Laboratory compaction	Compaction energy	Intermediary	Intermediary	Intermediary	Intermediary
	Maximum density (g cm^{-3})	1.390	1.390	1.390	1.390
	Optimum humidity (%)	33.4	33.4	33.4	33.4
Grading	Very coarse (%)	0.14	0.14	0.14	0.14
	Coarse/Medium (%)	5.04	5.04	5.04	5.04
	Medium (%)	-	-	-	-
	Fine (%)	7.31	7.31	7.31	7.31
Sedimentation	Silt/Clay (%)	87.31	87.31	87.31	87.31
	Silt (%)	-	-	-	-
CBR (%)		3.2	29.06	49.38	43.03
Expansion (%)		0.78	0.63	0.26	0.65

CBR: California Bearing Ratio

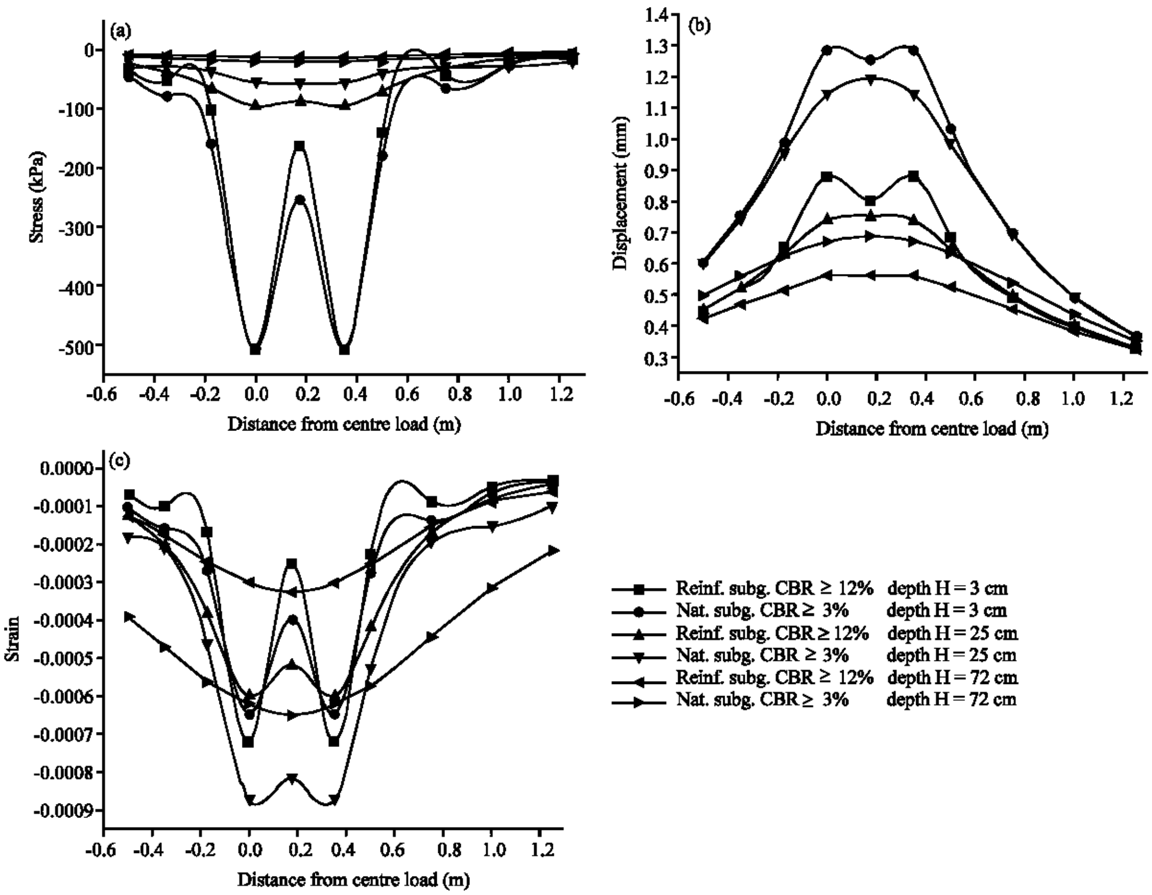

Fig. 1: Pavement responses comparisons between pavement 1 (with stabilized subgrade, CBR ≥ 12%) and pavement 2 (without subgrade stabilization, CBR ≥ 3%). (a) Vertical stress; (b) Vertical displacement; (c) Vertical strains

increases; the stress response in pavement 1 (due to improvement made on subgrade) is small than in pavement 2. Similar phenomena happens in Fig. 1b and 1c; Fig. 1b, the vertical displacements are very high on the surface and decrease as the depth increase and Fig. 1c, the vertical strains on the asphalt layer are very small when compared with elastic layers (base, subbase or subgrade). These phenomena indicate that the pavement responses are stronger dependent on the subgrade bearing capacity (subgrade layer elastic or resilient modulus).

CONCLUSIONS

The research on LCR concludes the followings:

- Only when 2% of Portland cement was added to natural yellow clayey soil, the bearing capacity (CBR) increased from 3 to 29%.
- The CBR of natural yellow clayey soil of 3% was improved to 49% by adding a 2% of cement and 5% of ECOLOPAVI. Similar result could be got by adding 6 to 7% of cement in conventional practices (cement or lime stabilizers). Thus, use of ECOLOPAVI is cheaper.
- The pavement response (evaluated by ELSYM 5) confirmed that it is dependent on subgrade layer elastic or resilient modulus as can be seen in Fig. 1a-c), as the depths increase, the stresses, displacement and strains decreased; it also shows that the subgrade elastic modulus plays an important role on pavement response. The results of two pavements (one with subgrade CBR ≥ 3% and another with subgrade CBR ≥ 12%), show that the structure with subgrade CBR ≥ 12% gave low stress, displacement and strains than that with CBR ≥3%.

- When the rate of cement was increased up to 2.5% the result of natural soil + 2.5% of cement + 5% of ECOLOPAVI shows that if the percentage of cement is higher than 2%, the value of CBR was 43% slightly lower; this was not expected. Thus, further studies on this stabilizer are recommended.

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