STABILIZING CLAYEY SOILS OF CAMEROON’S FAR NORTH REGION

by Jana Publication & Research

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ABSTRACT – Soil's geotechnical and mechanic features have significant impacts in road construction. Lift tests carried on clayey soils in the Far North Region of Cameroon revealed low levels of lift values. In order to improve these values, 2%, 4% and 6% of lime and cement were added to the initial material. Trials carried out in order to measure the plasticity index, density and the CBR index of various mixes of karal and sandy clay revealed a sharp improvement of these parameters. In fact, results attained indicate that with a 6% content of binding agent, the karal-lime blend moves from 19% to 14%, and that of karal-cement from 19% to 9.7%. As far as the sandy clay-lime blend is concerned, it moves from 15.3% to 14%, and the sandy clay-cement mix from 15.3% to 10.8%. Maximum density is obtained with a binding agent content of 4%. With cement, it actually moves from 1.85t/m^3 to 2.08t/m^3 when karal is mixed with cement, and from 1.88t/m^3 to 2.01t/m^3 for the sandy clay-cement blend. For a 6% content of binding agent, karal's CBR index increases from 6 to 24 for the karal-lime mix, and from 6 to 27 for that of karal-cement. With the same content of the binding agent, the CBR index of the sandy clay-lime mix moves from 13 to 39, and from 13 to 62 for the sandy clay-cement blend. This study reveals that with a 300% increase, cement has a higher impact than lime on materials used.

KEY WORDS: Clay, Lime, Cement, Density, CBR

1. Introduction and problem

Soil plays a critical role in road construction. Consequently, soil should undergo trials so as to determine their capacity to bear the load they are subjected to. The characteristics of low lift materials must be improved for them to be used efficiently; this is the case of clayey soils which are likely to undergo the phenomenon of shrinkage-swelling. This type of soil cover quite large surface areas all over the world, and under very contrasted seasonal variations (Cameroon's Karal or Berbéré from Choa Arabs, equivalent to Moroccan shoots, black-cotton soils and Indian regurs, margalithic soils from Indonesia. They cause serious damage on constructions and roads due to the high voluminal variation they are subjected (ISTED, 1988).

The northern part of Cameroon, especially the Far-North Region, and more specifically National Road No.1A (Maltam-Fotokol) in the Logone and Chari Division faces that phenomenon of shrinkage-swelling (Figure 1).

Figure 1: Shrinkage-swelling phenomenon in the locality of Maltam (Baana, 2020)

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The seriousness of this phenomenon caused civil engineers to design more or less sustainable solutions capable of mitigating the consequences of the shrinkage-swelling phenomenon. In some particularly adverse cases, the Engineer is obliged to remove thousands of cubic metres of clayey soils and to replace them with substitution materials, despite the high cost of this operation (A. Le Roux, 1969). Conversely, these soils have to be improved upon through techniques aimed at increasing their physical and mechanic properties. One of the techniques used is to stabilize these soils with hydraulic binding agents such as lime and/or cement.

The main objectives of these binding agents are first to improve the soil's handiness by reducing the plasticity index (PI) and the volume change characteristics, and second, to increase the long-term resistance of the soil treated (Abdelmoumen and al, 2018).

As far as our case study is concerned, we are going to use lime and cement as binding agents and to determine the quantities that produce the best geotechnical and mechanic features, by determining the plasticity index, the density at Proctor Optimum and the CBR index.

2. Methodology

2.1. Materials

2.1.1 Soil

Soils used in this study come from two drills carried out on No.1A National Road linking Maltam to Fotokol in the Far North Region of Cameroon, and more precisely in the Logone and Chari Division. Sites' geographical coordinates (Karal and sandy clay) are as follows respectively: 12°17'38'' North latitude and 14°35'43'' East longitude, and 12°12'38'' North latitude and 14°42'53'' East longitude.

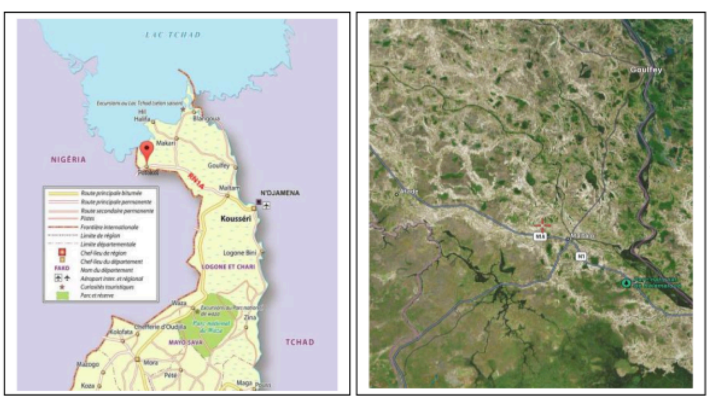

Figure 2. *Location of drilling sites of samples in the Far North Region of Cameroon*

These soils were taken from a depth varying between 0.5 and 1.5 metres, and their initial characteristics are shown in Table 1.

Table 1. *Parameters for the identification of samples under study.*

Sample	Natural water content W_{nat}(%) W_p(%)	Liquidity threshold W_l(%)	Plasticity threshold W_p(%)	Plasticity index I_p(%)
Karal (K)	20.5	36	17	19
Sandy clay (A)	11.79	40.3	25	15.3

2.1.2 Lime

The lime used is hydrated lime produced by the ROCA company located in the city of Figuil in the North Region of Cameroon. Its chemical properties are presented in Table 2.

Table 2: Chemical properties of the lime used.

Name	Percentage
Slaked lime $Ca(OH)_2$	95.4%
Magnesium oxide MgO	1.3%
Silicon SiO_2	1.3%
Iron oxide Fe_2O_3	1.2%
Aluminium Oxide Al_2O_3	0.5%

2.1.3 Cement

The cement used is of 42.5R type and is produced by the CIMENCAM cement works from Figuil in the North Region of Cameroon.

2.2 Laboratory equipment

As concerns laboratory equipment, we used the following:

- A screening line to sift soil samples;
- Equipment for sedimentometric tests;
- Casagrande equipment to determine consistency thresholds:
- Equipment and machines to carry out Proctor, modified Proctor and CBR tests;

2.3 Method

Two types of soils were used: karal and sandy clay. In order to determine the effects of cement or lime on the geotechnical performances of both soils; each type of soil was mixed with cement (or lime) contents of : 0%, 2%, 4% and 6%. We obtained the sixteen (16) samples in Table 3 below.

Table 3 : Mixes used for stabilized soil.

Blend	Symbol Karal/binding agent blend		Symbol Sandy clay /binding agent blend		Percentage	
	Lime	Cement	Lime	Cement	Material (%)	Binding agent (%)
0%	KCh0	KCi0	ACh0	ACi0	100	0
2%	KCh2	KCi2	ACh2	ACi2	98	2
4%	KCh4	KCi4	ACh4	ACi4	96	4
6%	KCh6	KCi6	ACh6	ACi6	94	6

2.3.1 Tests carried out

Granulometric and sedimentometric trials were carried out on the karal and sandy clay samples in line with the procedure set by the ASTM D 422-63 standard.

In order to determine the effects of cement and lime on both soils, we carried on the following tests over the sixteen blends (Table 3):

- Consistency threshold tests following the procedure indicated in the ASTM D 4318 standard.
- Modified Proctor test and immediate CBR and CBR after 4-day immersion test were carried out following the procedure indicated by standards NF P94-093 and NF P 94-078 respectively.

3. Results and discussion

3.1. Granulometry

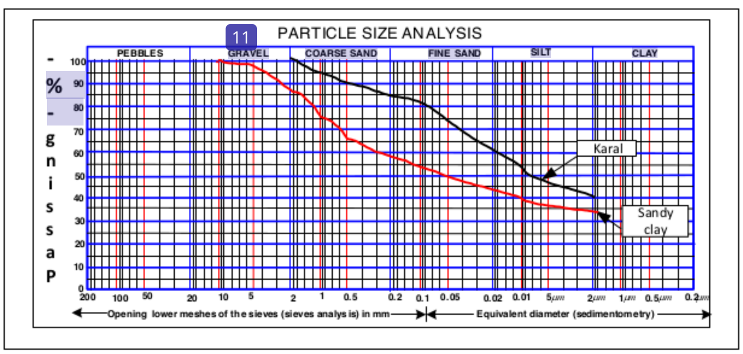

Figure 3. *Granulometric analysis results.*

Granulometric analysis' results which are summarized in Figure 2 reveal that materials are clayey. These clay contents have been confirmed by works carried out by D. Martin and al (1966) showing that Northern Cameroon's soils are:

- Sandy-clayey (10-25% of clay) on the surface and clayey-sandy (25-40% of clay) deeper for soils derived from gneiss, embrechite and sometimes mica-schists.

- Clayey-sandy (25-35% of clay) on the surface and clayey (40-60% of clay) deeper for soils derived mica-schists, amphibol schists (green rock).

3.2 Atterberg Thresholds

Results from tests carried out are summarized in Table 4.

Table 4: Measured consistency tests of blends.

Materials	LA	0%	Lime			Cement		
			2%	4%	6%	2%	4%	6%
Karal K	W_l	36	35,3	33,7	33	35	34	33
	W_p	17	18	18,7	19	20	21,4	23,3
	I_P	19	17,3	15	14	15	12,6	9,7
Sandy clay A	W_l	40,3	40,3	40,2	39,9	39,8	38,1	37,9
	W_p	25	25,1	25,2	25,9	25,5	26,4	27,1
	I_P	15,3	15,2	15	14	14,3	11,7	10,8

Consistency threshold tests caried out on Karal K and sandy clay samples, carried forward on Cassandre's plasticity abacus indicate that both soils are moderately plastic clays (Figure 4).

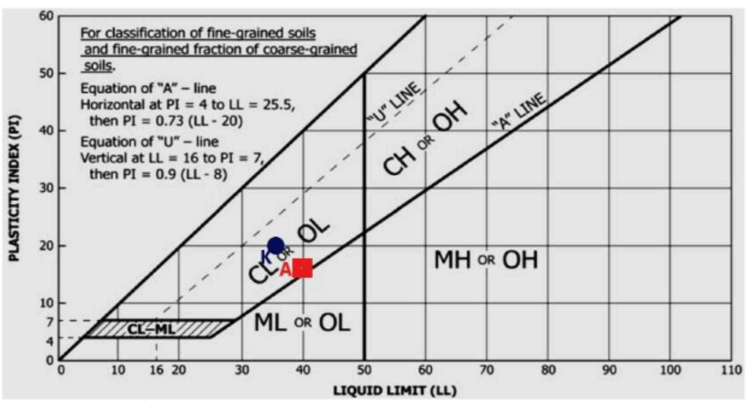

Figure 4. ***Nature of materials according to Cassandre's plasticity abacus.***

Looking at results in Table 4, one can notice that the plasticity index reduces as the cement percentage increases for both materials. The same behaviour was noted by many researchers such as A. Le Roux (1969), Jules A. SAGNON (2024) and SEYBATOU DIOP (2014).
The reduction in the plasticity index is due to the flocculation of stabilized soil particles resulting from the alteration of the water layer surrounding clay minerals present in the soil.
As far as lime is concerned, the plasticity threshold reduces but not so significantly.

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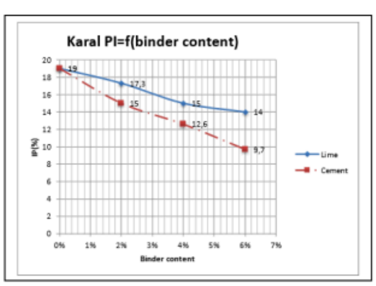
Plasticity index variation according to the binding agent content is provided in Figures 5 and 6.



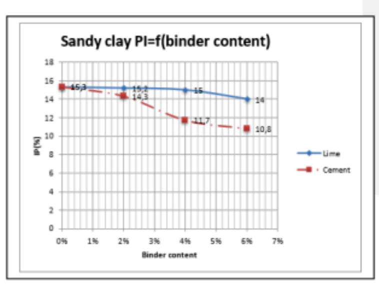


Figure 5. *Evolution of blends' plasticity index according to the binding agent's percentage.*

One can notice that irrespective of the binding material used, the plasticity index reduces. The plasticity index decreases as the binding agent's percentage increases. With the addition of 6% binding agent, karal's plasticity index which is 19% moves to: 14% (for lime) and 10.8 (for cement).
These results corroborate works carried out by Zouhair Attima (2014) who notes that the plasticity index I_P strongly decreases with the quantity of lime added up to 5%, then slightly reduces before stabilizing for higher percentages.
This phenomenon could be explained by:

- As concerns lime, a change in the quality of lime through a change of alkaline cations (Na^+, K,..) by $Ca2^+$ cations brought in by lime; this develops electric forces that lead to a concentration of fine clayey particles into bigger and crumbly particles (Equine Engineering, 2004).
- In the case of cement, the flocculation reaction of clay grains due to the presence of $Ca2^+$ and OH^- which play a major role by reducing the thickness of the double layer.

Also, we notice that cement has more impact on both materials than lime. Reduction, for a 6% increase in the binding agent's content, is of 48.95% (Karal-cement) and 29.41% (sandy clay-cement) against 26.32% (Karal-lime) and 8.50% (sandy clay-lime).

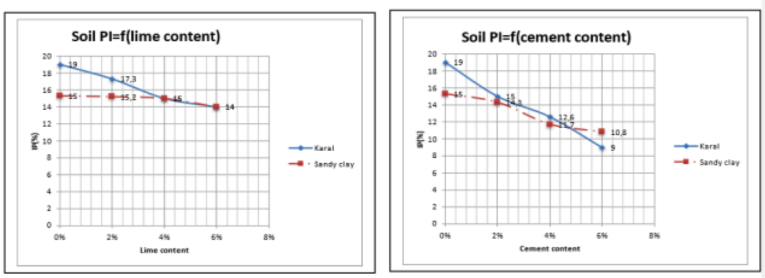


Figure 6. ***Evolution of the plasticity index of blends according to the binding agent's percentages***

It is noticed that both soils are suitable for being improved with lime or cement as confirmed by Fréderic Collin (2013); candidate soils to be treated with lime had a minimum fraction at 75µ m of 25% and their plasticity index above 10.
Results show that plasticity indexes have significantly reduced with the addition of 6% of binding agent.
According to these results, the addition of cement reduces the plasticity index. This reduction indicates that there is an improvement in the soil's handiness. This is due to the chemical reaction between cement and soil. Also, the addition of lime into the material within the same quantities produces a reduction of the plasticity index. The consequence is the evolution of the plasticity domain towards dry state.

In conclusion, the addition of the binding agent (lime or cement) into the material leads to a reduction in its water content. This reduction can be explained by the flocculation reaction due to the presence of Ca^{2+} and OH^- which improves consistency.

3.3 Proctor Optimum's dry densities

Dry densities at Modified Proctor Optimum of karal blends (sandy clay) with binding agents according to their percentages are shown in Table 5 and Figures 7 and 8.

Table 5. *Values of optimum dry densities and water content of various blends of K and A at Modified Proctor Optimum*.

Matérials	OPM	0%	Lime			Cement		
			2%	4%	6%	2%	4%	6%
Karal K	Wopt (%)	12.1	10.1	9.4	11.4	12.1	8.1	6.8
	γ_{opt} (t/m^3)	1.85	1.87	1.9	1.89	1.89	2.08	2.05
Sandy Clay A	Wopt (%)	10.7	11.3	12.1	7.3	9.8	8.7	10.1
	γ_{opt} (t/m^3)	1.89	1.91	1.92	2.00	1.97	2.01	2.00

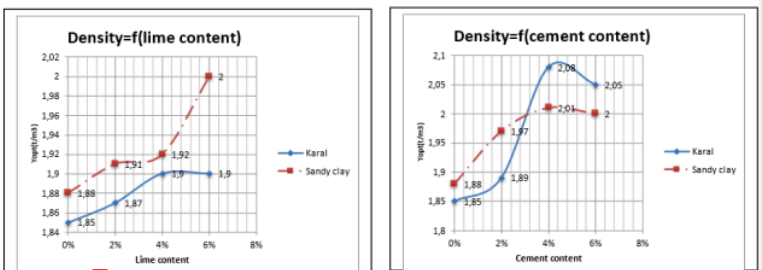


Figure 7. *Dry density at Modified Proctor Optimum for blends, according to the binding agent's percentage*

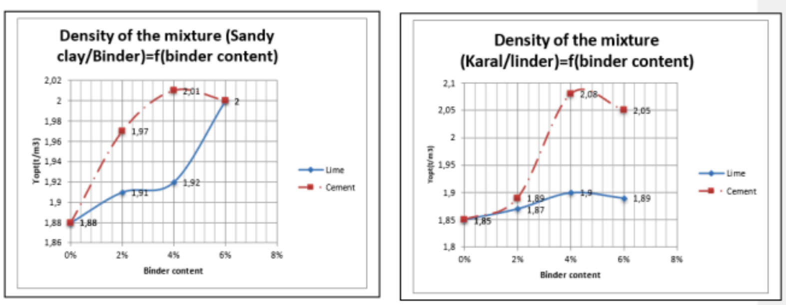


Figure 8. *Dry density at Modified Proctor Optimum for blends, according to the binding agent's percentage*

Table 5 and Figures 7 and 8 show that density increases as the binding agent's content increases. For Karal K, density which stands at 1.85t/m^3 moves to 1.90t/m^3 for a lime percentage of 4% (resp. 2.08 t/m^3 with cement) and 1.89 t/m^3 for a lime percentage of 6% (resp. 2.05t/m^3 with cement).

For sandy clay, density which stands at 1.88t/m^3 moves to 1.92t/m^3 for a lime percentage of 4% (resp. 2.01t/m^3 with cement) and 2.00t/m^3 for a lime percentage of 6% (resp. 2.00t/m^3 with cement). Also, we notice that optimum density is obtained with a 4 to 6% of binding agent.

If we consider a 4% rate of binding agent, the increase of the blend's (Karal-Binding agent) is of 2.70% with lime (resp. 12.43% with cement). As far as the sandy clay-binding agent blend, the increase in density stands at 2.12% (resp. 6.91% with cement).

From the above, one could say that cement has a greater impact on the blend's density than lime. This situation can be explained by the fact that these materials contain a quite high quantity of sand. As a matter of fact, cement's hydrated constituents bind sand grains together, thus building numerous and strong bridges, thus increasing the bearing capacity and the mechanical resistance.

3.4 CBR indexes

Results showing CBR index values after immersion are summarized in Table 6 and Figures 9 and 10.

Table 6. *CBR Evolution according to the binding agent's percentage.*

Materials	0%	Lime			Cement		
		2%	4%	6%	2%	4%	6%
Karal K	6	18	21	24	16	21	27
Sandy clay	13	23	32	39	29	59	62

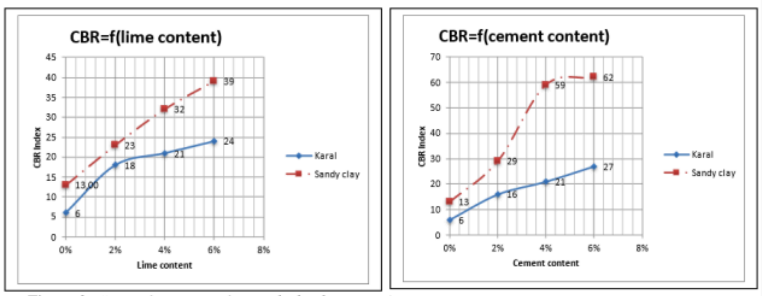


Figure 9: *CBR indexes according to the binding agent's percentage.*

One can notice that CBR indexes increase depending on the percentage of the binding agent.

Karal's CBR index which initially stood at 6 moves to 18, 21 and 24 respectively, for lime proportions of 2, 4 and 6%. If we consider a 6% percentage, we obtain a 300% increase. As far as sandy clay is concerned, and for the same percentages, the CBR moves from 13 to 23, 32 and 39. With a 6% percentage, we obtain a 200% increase.

These results corroborate those of Zouhair (2014), which confirm an outstanding increase in CBR index values with a 5% proportion of lime. When lime gets into contact with a material containing silicates and aluminates, hydrated calcium silicates and aluminates are produced which, while turning into crystal form, create a real "clutch" between materials in contact, as is the case with the cement catch. This reaction, referred to as "pozzolanic", entails an increase in simple pressure resistance, CBR index and stability at freezing conditions.

The karal CBR index which was initially at 6, moves to 16, 21 and 27 for lime indexes of respectively 2, 4 and 6%. If we consider a 6% proportion, we obtain a 350% increase. As far as sandy clay is concerned, for the same proportions, the CBR moves from 13 to 29, 59 and 62. With a 6%

proportion, we record a 376.92% increase. These results are in line with those of Seybatou Diop (2014), which show that the CBR increases depending on the cement dosage.

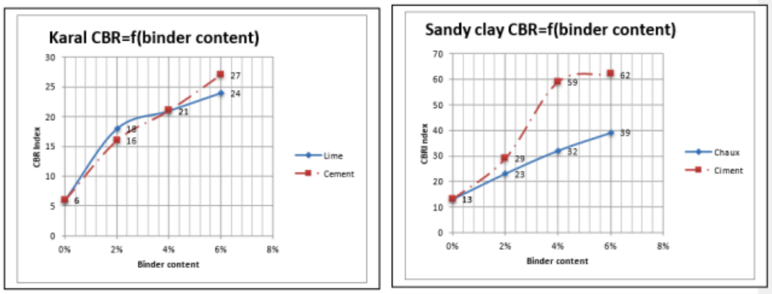


Figure 10. *CBR indexes for the blend depending on the percentage of the binding agent.*

Figures 8 to 10 reveal a variation in the CBR indexes depending on the binding agent content (lime and cement). Curves indicate that these indexes grow as the content of the binding agent increases.
Therefore, for the Karal, we move from a CBR index between 6 and 24 with a lime content of 6%, which represents a 300% increase. With the same content in cement, we move from 6 to 27, that is a 350% increase.
As concerns sandy clay, we move from a CBR index of 13 to 39, with a lime content of 6%, that is a 200% increase. With the same cement content, we move from 13 to 62, an increase of 376.92%.
Studies carried out by Jules Anicet Sagnon (2024) corroborate these results; stabilized at 5% with cement and lime, the bearing capacity of fine soil studied then moves from low to high (lime) and to very high (cement).

Results obtained and summarized in Table 6 and Figures 9 and 10 give us the following information:

- CBR varies according the binding agent's percentage
- The more the percentage of the binding agent increases, the more the CBR grows.
- The soil-cement blend produces higher CBR index values than those of the soil-lime blend.
- Higher CBR index values obtained are as follows: 24 (with lime) and 27 (with cement) for the karal, 39 (with lime) and 62 (with cement) for sandy clay.
- The mix with cement leads to a 350% for karal and 376.2% for sandy clay.

On the whole, we have noticed that the binding agent improves the blend's properties. The CBR increases significantly with a 6% content of a binding agent. This phenomenon can be explained by the fact that the consistency of the blend, with the reduction of fines as well as the addition of a quantity of binding agent (2 to 6%), contribute in reducing swelling and improving the bearing capacity which increases the resistance of the stabilized soil.

4 Conclusions

The addition of a binding agent (lime or cement) to the initial material improves clayey soil's mechanic properties. The plasticity index decreases as the binding agent's percentage grows. Moreover, cement has greater effect on both materials than lime. The drop in plasticity is of 48.95% (Karal-cement and 29.41% (sandy clay-cement).

The Optimum dry densities at Modified Proctor tests for these soils increase when a binding agent is added. With a 4% rate of binding agent, the maximum dry density obtained is of 1.9t/m^3 (Karal-

Lime), 2.08t/m^3 (Karal-Cement), 1.92t/m^3 (Sandy Clay-Lime) and 2.10t/m^3 (Sandy clay-cement). The soil-cement blend produces an appreciable optimum density. The soil-cement blend offers a better optimum density than lime.

CBR indexes vary significantly depending on the binding agent's content. We noticed that with 6% of binding agent, we obtained clearly higher values than those with initial materials (without mixing). Karal's CBR index moved from 6 to: 24 (Karal-lime) and 27 (Karal-Cement); that of sandy clay increased from 13 to 39 (Sandy clay-lime) and 62 (Sandy clay-Cement). The effect of cement on the initial material is more pronounced than that of lime. The increase is higher than 300%.

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