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Mechanical and Geotechnical Behaviour of Improved Sandy Clay Soil for Road Pavements in Offshore Sedimentary Basins

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ABSTRACT: Road projects require a lot of earthworks. Sometimes, the soil in place has an insufficient bearing capacity; hence, the need to look for soil with required specifications. When a material is too far from the construction site, its transportation costful and time spending to the project. In offshore sedimentary basins, materials mostly available are sandy clay soils. This paper focuses on the improvement of the bearing capacity of sandy clay soil for different road pavements. Two solutions were investigated: lithostabilisation of sandy clay soil with volcanic rocks and cement stabilisation at different percentage in various curing conditions. Physical, geotechnical and mechanical properties were assessed on samples. It was found that, at 25% mix with volcanic gravel, sandy clayed soils are useable for the T2-T3 subbase layer and at 35% the mix can be stabilised with cement for the T2-T3 base and T4-T5 subbase layers. 4% cement dosage is the optimum for the three pavement layers. This dosage can be reduced to 2% for the T2-T3 subbase, if the negative impacts from environmental waters are counteracted. With a close look on the respect of prescribed procedures, sandy clayed soils in offshore sedimentary basins are useable for the construction of pavement layers.

KEYWORDS: sandy clay soil; lithostabilisation; cement stabilisation; curing conditions; bearing capacity;

I. INTRODUCTION

In civil engineering, pavement construction is based on the design of the sub-base and base layers such that when put in place, they will protect the subgrade from deforming. The materials to be used, to reach the target properties should be nearer and cheaply available to reduce the cost and time of construction of the road layers.

The CEBTP guide [1] proposes specifications for the use of the different type of materials for each pavement layer. Inshore sedimentary basins (campo basin) are characterised with ferralitic soils, poor in silicone and well drained (Sands with clay matrix at the top and clayed soil at the bottom), but hydromorphic when submitted to excess water. For the construction of most roads in such regions (ex. Douala [2]), the company usually faces the problem of insufficient nearby soil sites with adequate mechanical properties, for the sub-base and base layers. They are expected to transport the soil from distant sites, which is not to the advantage of construction cost and time [3]. Researches for methods to upgrade the mechanical properties of sandy – clay soils [4] for the base and sub-base layers of the road structure, will lead to an economical road construction solution.

Soil stabilization is a general term for any physical, chemical, mechanical, biological or combined method of changing a natural soil to meet an engineering purpose [5]. In civil engineering, soil stabilization is a technique to refine and improve the engineering properties of soils [6]. With it, strength (resilient modulus, shearing strength and compressive strength) improvement may be offered. The mitigation of volume instability, swelling potential and shrinkage will offer erosion and sediment control. In addition, the reduction of clay/silt particles, plastic index, permeability, compressibility and deformation [7] will improve the durability to resist environmental conditions. Furthermore, dust control, water repelling and waterproofing may be offered with soil stabilisation.

A solid road can be constructed even in a marshy land [8]. To propose solid road structures, using sandy clay soil a close look, on the stabilisation method to be used is quite necessary. It should be proven that the proposed stabilisation methods will enable reach the target properties in the laboratory. Many techniques on soil stabilization have been developed among which are [9]: Litho-stabilization [10], Stabilization of soils with cement, Lime, pozzolana, fly-ash and bitumen [11, 12], Thermal or electrical stabilization [10], Stabilization of soils with organic stabilizers [13], Bio-cementation [14], Chemical stabilization with polymers, sodium silicates, calcium chloride and sodium chloride [15]. Among the methods prescribed in reviews, lithostabilisation and cement stabilisation are proposed in to enhance the properties of lateritic soils for its use on sub-base and base layers [3, 1]. Sandy clayed soils are mostly stabilised for the subgrade layer, due to the swelling potential of clay particles contained in it. The CEBTP prescribed 3 decades ago, methods (Lithostabilisation and cement stabilisation) to use sandy clay soils for the subbase and base layers. It is important to confront - confirm - update these solutions for their use in the present.

Mechanical stabilisation (lithostabilisation) entails the mixture of two or more types of natural soil (soil gradation is modified [16]) in an attempt to improve the properties of the soil, by combining the engineering properties of the constituents [17]. Aggregates (D ≥80µm), usually consist of strong, well-graded and somewhat angular particles of sand and gravel which serves as a skeletal framework providing internal friction and incompressibility to the soil. Binders (D < 80 µm), composed primarily of clays and silts, provide cohesion, plasticity and imperviousness to the soil. Compaction of the soil (for well graded soils Cu >15 and 1≤ Cc ≤3) with an induced frequency near the natural frequency of the host soil material at optimum moisture content, ensures maximum dry density, decrease in void ratio and increase in cohesion (C) and internal friction angle (∅) [18]. Lithostabilisation therefore enable the achievement of a dense well-graded material by mixing and compacting two or more soils and/or aggregates [10].

Cement (ordinary Portland, blast furnace, sulphate resistant and high alumina) is the oldest binding agent used for soil stabilisation. Its choice depends on the soil, the target strength and the environment [19]. Soil-cement can be defined as the mixture of soil, measured amounts of cement and water, compacted, to amend the mechanical and engineering properties of the soil (strength, permeability, volume stability, durability and minimal moisture variations) [20]. This depends on the reactions, producing cementitious products (calcium-silicate-hydrate, C-S-H & calcium-aluminate-hydrates, C-A-H) [21, 18].

Lithostabilisation and cement stabilisation can be assets to promote local materials that sometimes show inadequate mechanical properties to be used for named pavement layers [22].

This paper is aiming to investigate the use of improved sandy clay soils for the construction of the subbase and base layers for roads pavements. Two solutions are investigated through the improvement of certain geotechnical characteristics, with a close look at the impact of the curing conditions. In the first step, sandy clay soils is mixed with volcanic gravels (lithostabilisation) at 20%, 25%, 30%, 35% and 40%. In the second step, sandy clay soils is stabilised with cement Portland (1%, 2%, 4% and 6%) and cured in different conditions (covered in a room, immerged in pipeborne water and immerged in culvert water). Specifically, it will be a question of showing how the bearing capacity incrementation and plasticity are influenced by lithostabilizing and / or cementing sandy clay soils, rendering possible its use on the base and subbase layers. The sandy clayed soil will be lithostabilised in this case with volcanic gravels (pozzolana) from Njombe Pendja and cemented with cement from CIMENCAM. The bearing capacity of lithostabilised samples are tested with the CBR test and the plastic index with the Atterberg limit tests. The gradation of the samples is obtained from the particle size distribution. The strength of cemented test pieces after 7 days cure is analysed are with the UCS test. The effect of immersion of road layers and the effect of the water in which it is immerged will be demonstrated. For this, 9 pieces are cured in a room (covered) for 3 days. Then while 3 of them are immerge in Pipe borne water, 3 are immerged in culvert water and 3 are left in the room for 4 more days. The CEBTP specifications (1972 and 1984) relating to the dimensioning of roads in tropical areas are used to check the conformity of the results obtained on the mixtures with a view to their possible use in pavement layers of a road class. It will also be explained why 7days strength are useable as reference for the study of cement treated materials.

II. MATERIALS AND METHODS

A. *Materials*

1) *Sandy clay soil:*

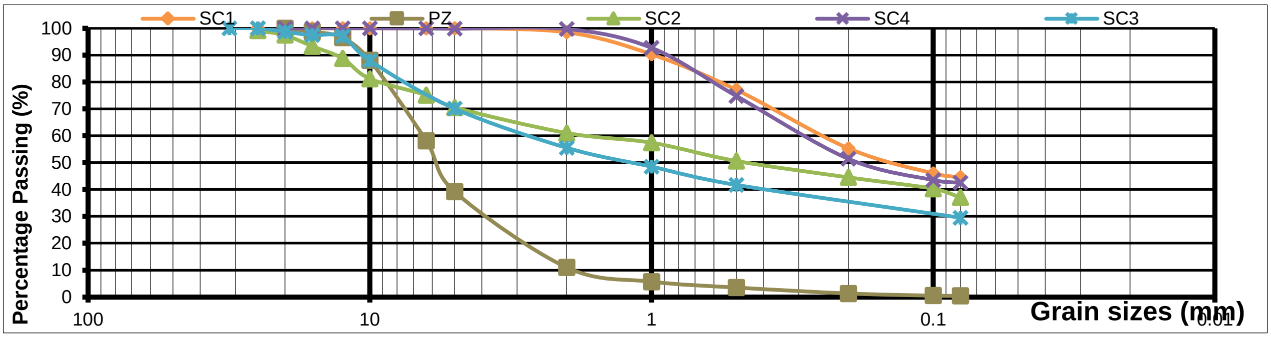
Sandy clay soil used in this study was collected from Douala (Cameroon), transported, and prepared in the laboratory according to XP P 94-202. The SC soil was selected (Fig 1a) to be ameliorated for its use as subbase and base materials Its geotechnical characteristics (Fig 1 b) improves the probability of attending the target results for subbase and base layers with a minimum of coarser materials (pozzolana).

2) *Pozzolana (PZ):*

Pozzolana utilized in this investigation, was collected from NJOMBE PENJA quarry Pozzolana is on a basic point of view, a clay mineral. The basic structural units of most clay minerals are silicon–oxygen tetrahedron and aluminium–hydroxyl octahedron, both with valency imbalances resulting in net negative charges [23]. The basic units combine to form sheet structures. The tetrahedral units combine by the sharing of oxygen ions to form a silica sheet, which retains a net negative charge. The octahedral units combine through shared hydroxyl ions to form a gibbsite sheet, which is electrically neutral [24]. These two sheets offer strength to the treated soil material, depending on the added percentages (Table 3).

3) *Portland cement:*

The Portland cement used in this investigation is classified as 42.5R, with an initial setting time of 2 hrs 50 mins and final setting time of 3 hrs 40 mins [25]. The chemical composition of Portland cement and predicted mineralogical composition of its oxides [26] are presented in **Table 1**. From cement characterisation, CMI is good for road stabilisation as it will bring about enough moisture content with its water absorption abilities and thus complete hydration reactions [27]. Moreover, the cementing compounds are based on the availability of CaO, which is highly available in CMI (62.2%), for the formation of *Calcium silicate hydrate* and *Calcium Aluminate hydrate* cementing bonds.



(a)

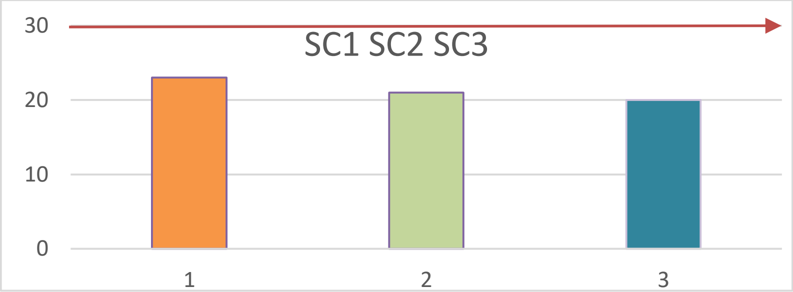
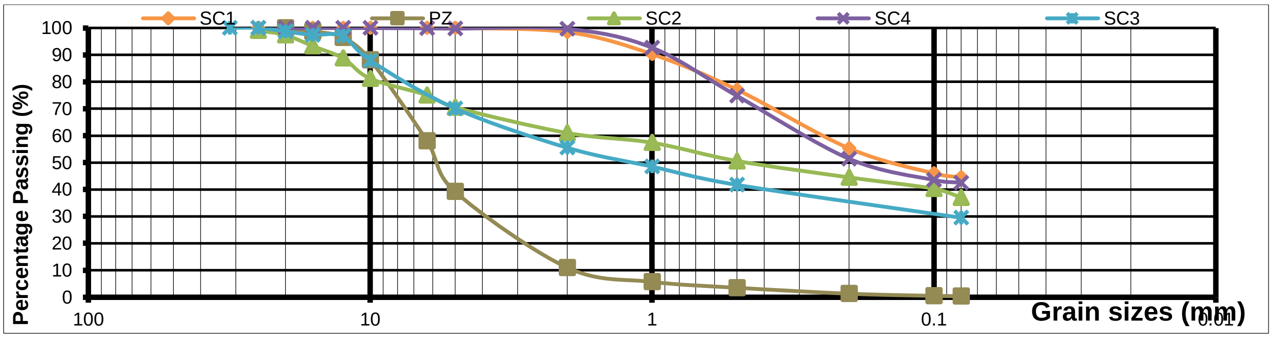


Fig 1 Characterisation of investigated Douala sandy clay soil samples and pozzolana (a) Grain size distribution curves (b) CBR indexes

(b)



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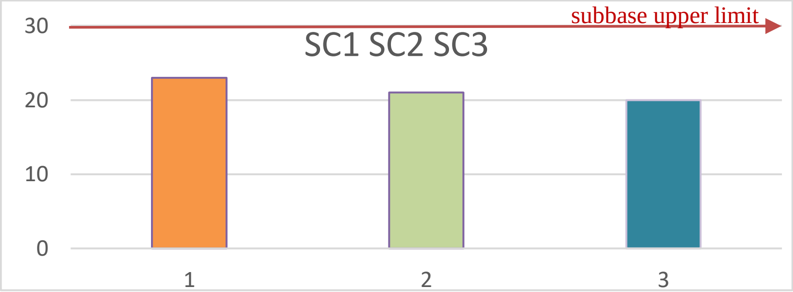

Fig 1 Characterisation of investigated Douala sandy clay soil samples and pozzolana (a) Grain size distribution curves (b) CBR indexes

Table 1 : Chemical Composition, Specific Surface Area And Calculation Factor For Different Cement [26]

Cement	Composition	Cement	Composition
CaO	62.23%	TiO_2	0.33%
SiO_2	19.22%	ZrO_2	0.09%
SO_2	5.01%	BaO	0.04%
Al_2O_3	3.34%	PbO	0.01%
Fe_2O_3	2.50%	Cr_2O_3	0.01%
H_2O	2.50%	NiO	0.01 %
K_2O	0.95%	Specific surfaces area	1.26 g/m^2

The binder content shall not be less than the minimum binder content (see

Table **2***)* as specified by EN 14227-1, with respect to the nominal aggregate size.

Table 2 : Binder Content With Respect To Nominal Aggregate Size

Maximum nominal aggregate size (mm)	Minimum binder content % (by mass)
> 8.0 to 31.5	3
2.0 to 8.0	4
< 2.0	5

B. *Experimental method*

1) Samples production:

The amount of each constituent is calculated as a percentage of the total dry mass required for each test (Table 3). The mass of each constituent is weighed after the quartering of all the material in the bag. The quartering maximizes the probability that the small sampled material is representative (has the same particle size grading) of the sample in the bag. Material samples once weighed are well mixed before each test.

2) Lithostabilisation:

The particle size curve determines the suitability of the material, joined to the absence of segregation and the compactness of the material. It is tempting to define an ideal particle size curve and a zone within which the particle size curve should always be located [28]. The analytic form of grading curve’s correction $P100 = (\frac{d}{D})^n$

(1) permitted to bring out the proportions of the theoretical curve and the maximum and minimum theoretical particle size grading.

$$\frac{P}{100} = (\frac{d}{D})^n \qquad (1)$$

P: percentage of passing through the sieve of diameter d

d: diameter of each sieve

D: diameter of the biggest particle

n: percentage of fillers

From the investigations and based on the grading curve correction formula, five formulations were chosen with an objective to maximize the host material. (See Table 3)

3) Cement stabilisation :

Cement dosages of 1%, 2%, 4% and 6% (see

Table 5) have been used based on the recommendations of the CEBTP [1] and respecting the minimum binder content percentage by mass. The material is mixed with cement 2 to 3 turns and then evenly wetted to the optimum water content of SC. The wetted sample is mixed 3 to 5 turns and compacted in 5 layers at 56 strokes per layer (maximum energy according to the norm NF P 94-078 [29]), in a split mould. The compacted material is levelled and the mould is disassembled. The test piece is painstakingly stored to the curing conditions.

4) Curing conditions and procedure :

During the geotechnical characterisation of lithostabilised samples, the optimum water content and maximum dry density of each sample is determined with the PROCTOR test. Then, for the Californian bearing ratio (CBR) test each sample is humidified to its optimum water content. The samples are then compacted as described in the standard norm [29]. The test specimens are immerged in pipe borne water for 4 days. On the fourth day, they are removed and placed inclined with the charges on the test pieces, for at least 1hour, to loose out the excess water.

Table 3 : Composition of lithostabilised samples

	Reference	Lithostabilisation				
Label	P0	P1	P2	P3	P4	P5
Composition	sandy clay soil ‘SC’	80% SC + 20% PZ[1]	75% SC + 25% PZ	70% SC + 30% PZ	65% SC + 35% PZ	60% SC + 40% PZ

Table 4 : Composition of cemented samples

	Reference	Cement stabilisation

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[1] PZ = pozzolana

Label	P0	Pa	Pb	Pc	Pd
Composition	sandy clay soil ‘SC’	SC + 1% cement	SC + 2% cement	SC + 4% cement	SC + 6% cement

Cement is closely and cheaply available everywhere thanks to the commercial activities of cement industries, and requires less maintenance cost. But its implementation is considered very difficult due to the setting time, formation of cracks and its high vulnerability to the amount of water used [4]. The implementation and curing time demands proper supervision [30]. Rain should be avoided, and evaporation of water should also be avoided. In addition to this, chemical composition of waters in the environment (a parameter that cannot be controlled), may affect the stabilisation [7]. A seven-day curing period is often used as a convenient reference for CTM [1], thanks to their rapid strength gain. To investigate on the impact of curing conditions, the test pieces were put in three different media (air, pipe born water and culvert water). In the air, three moulds were placed for the 7 days in a room at an average temperature of 25 ± 5 °C, pressure of about 1013 mb and covered with a polymer to minimize water evaporation. Six other moulds are immerged for 4 days (three in pipe born water and three in culvert water carried on the street), after 3 days in the same air conditions as above.

5) Physical characterisation:

Particle size distribution, Atterberg limits, specific gravity and maximum dry unit weight were carried out on each sample (See **Table 5**).

Table 5 : Program tests of the physical characterisation of stabilised samples

Types of tests	Parameters sought	Norm
Identification tests	Water content Specific gravity (G)	NF P 94-050 [31] NF P 94-054 [32]
Particle size distribution	Soil grain diameter % distribution for each size Uniformity coefficient (Cu) Coefficient of curvature (Cc)	NF P 94-056 [33]
Modified proctor	Optimum water content (w_{opm}) maximum dry unit weight (γ_{dOPM})	NF P 94-093 [34]
Atterberg limits	Liquide limit (LL), plastic limit (PL), plastic index (PI)	NF P 94-051 [35]

- Specific unit weight and specific gravity of soil

A sealable pycnometer of 900ml, a specific balance, a drying oven and clean water are used to determine the specific unit weight of soil. About 400g (medium and coarse-grained soils) are oven-dried. The empty pycnometer is weigh (W_1) followed by the pycnometer with dry soil added inside (W_2). 500 ml of water is then added and the closed content set aside for 4h before being shaken on hand for 20-30 mins. Next, the rubber stopper is removed, soil adhering is washed carefully into the jar and water is then added to the brim. The slip cover is then placed on the top of the jar taking care not to trap any air under the cover. The external surface is dried and W_3 is recorded. The jar is emptied, washed and filled to the brim with water for W_4 record. The specific gravity is then calculated

Dry soil weight $W_d = W_2 - W_1$
Solid soil volume $V_s = (W_4 - W_1) - (W_3 - W_2) / \gamma_w$
Specific unit mass $\gamma_s = W_d / V_s$
Specific gravity $G = \gamma_s / \gamma_w = W_d / (V_s{*}\,\gamma_w)$ (2).

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Specific unit mass $\gamma_s = W_d / V_s$
Specific gravity $G = \gamma_s / \gamma_w = W_d / (V_s{*}\,\gamma_w)$ (2)

- Particle size distribution

The relative proportion of the particle sizes is very important in determining the soil’s load-carrying capacity. About 5000g of soil is taken for the test. The soil is weight for initial mass (m_h). 500g of soil from the same sampling material is used to determine its water content (ω). The total dry mass m computed with equation m = $\frac{m_h}{1+\omega}$ $t_i = \frac{m_i}{m} \times 100$ $T_i = \sum_{i=1}^{i} t_i$ $P_i = 100 - T_i$ (3). The soil is then washed at the 0.08mm sieve to remove all fine (clay) soil particles sticked on the coarse-grained soil particles. The retained soil particles are then dried in the oven at 110 °C, for 24hrs. The series of sieves are aligned from the smallest screen at the bottom to the largest at the top with a bottom plate. The soil is poured at the top sieve and closed. The column of sieves is either mechanically or manually sifted. One sieve to the other is subdued and the retained material weigh (t_i). Finally, the cumulating percentage pass (P_i) is calculated m = $\frac{m_h}{1+\omega}$ $t_i = \frac{m_i}{m} \times 100$ $T_i = \sum_{i=1}^{i} t_i$ $P_i = 100 - T_i$ (3) and plotted against the sieve diameter.

$$m = \frac{m_h}{1+\omega} \qquad t_i = \frac{m_i}{m} \times 100 \qquad T_i = \sum_{i=1}^{i} t_i \qquad P_i = 100 - T_i \qquad (3)$$

- Density and optimum water content

Soil optimum load bearing is at maximum dry density. Soil compaction reduces air void content and grains are brought near each other to provide mechanical interlocking. This depends on water content, soil type, energy and technique used [36]. Proctor test is used to determine the relationship between water content and dry density of the material given a particular amount of compaction energy. It allows an estimate of the maximum dry density that can be achieved on construction sites and provides reference parameters for assessing the density of the compacted layer.

The test is done using cylindrical CBR mould with its corresponding compaction hammer, specified balance with 0.1g precision, drying oven, test bowls and plates. With the sampling machine, five samples of 6000g of well distributed soil are measured. Each sample is then well mixed and wetted with a percentage water weight, chosen such that after three percentage water content steps, the optimum water content should be crossed. The mould is weighed without its top and bottom (m_m) and its volume measured (V_{tot}).

The test consists of compacting five soil layers in a cylindrical mould by dropping a compaction hammer of a prescribed weight from a specified height, at 56 blows per layer. The soil in the mould is then levelled and the mould cleaned. The top and bottom of the mould are removed, to weigh the mould with the soil (m_{m+s}). A small soil sample is taken to determine its water content. The humid unit weight (γ) is calculated and dry unit weight (γ_d)$\gamma = \frac{m_{m+s} - m_m}{V_m}$ $\gamma_{dry} = \frac{W_{solid}}{V_{tot}} = \frac{\gamma}{1+w}$ (4) is computed for the 5 soil samples with increasing water content. The water content against dry unit weight is plotted, from which the maximum dry unit weight at the top of the curve is read with its corresponding water content.

$$\gamma = \frac{m_{m+s} - m_m}{V_m} \qquad \gamma_{dry} = \frac{W_{solid}}{V_{tot}} = \frac{\gamma}{1+w} \qquad (4)$$

- Atterberg limits

Fine grained clay and silts soils can be in four different states; soli, semi-solid, plastic and liquid states, with respect to their moisture content. These soils change their attributes or characteristics upon addition or expulsion of water content. The water content at which soil changes from one state to another is known as consistency limits or Atterberg limits [37]. Clay soils when added with water content expand in volume and upon variation of water content may shrink as well, depending on the structure or mineralogical characteristics of the soil. Silts, clay and sand have a different mineralogical character. While doing so, they have a variable value of shear strength which is a very important parameter of soil bearing capacity.

Liquid limit (LL) is the water content at which the clayey soil changes from plastic to liquid state. The liquid state is that in which soil doesn’t have any shear strength (it just collapses). It can be determined by Casagrande’s method. In this method, a special metallic bowl is used which is 10 to 12 cm diameter. The soil after mixing with suitable amount of water content, is mixed and placed in the device. A standard spatula is used to make a groove of 2mm in depth. The cup is rotated within the apparatus by rotating the handle and as a result of the impact gradually close over a distance of 12.7 mm. This test is repeated and a graph of number of blows against water content is drawn. From the graph, the liquid limit is determined as the water content at which 25 blows of Casagrande apparatus cause the groove to close over 12.7 mm.

The plastic limit (PL) is the moisture content at which the soil begins to behave like a plastic material. It defines the moisture content above which the water will destroy the cohesion of the soil. At plastic limit, the soil will crumble when rolled into thread of 3.2mm (1/8 in) in diameter. ASTM D4148 has standardized this method as determination of plastic limit of soil. In this method the soil is first taken as an ellipsoidal mass in weight of 1.5 to 2 grams. After that the mass is rolled between the palm or fingers and then on a glass plate with sufficient pressure, into a thread of uniform diameter throughout its length. The thread is further deformed to reach diameter to 3.2mm, with no cracks, taking no more than 2 minutes. Now break the specimen into several pieces and repeat the procedure until the time when soil can no longer be rolled into a 3.2 mm diameter thread with no cracks. The water content is determined and is termed the plastic limit. The plastic index (PI) is calculated PI = $\boldsymbol{LL - PL}$ **(5)** and plotted against the LL on the casagrande’s graph for interpretation.

$$\boldsymbol{PI = LL - PL} \qquad \textbf{(5)}$$

6) Geotechnical and mechanical characterisation

Geotechnical characterisation is only performed on the SC soil and the lithostabilised specimens (see **Error! Reference source not found.**). The bearing capacity of soils is related to the resistance to excessive deformation. It can be determined with the CBR test, a standardized penetration test in which a piston (diameter 50 ± 0,5 mm) penetrates soil specimen (compacted at 90%, 95% and 100% of the maximum density) at a fixed rate (rate of 1,27 ± 0,20 mm/min). As deformation occurs, penetration to failure is observed, recording the force causing it. Before compaction, a spacer disc (6 cm thick) is placed in the mould (18 cm height) to create the necessary space for placing a surcharge weight, which simulates the overlying layers in the road structure. The CBR value is expressed as a percentage of a standard load at fixed penetration depths of 2.5 mm ($I_{2.5}$) and 5 mm ($I_{5.0}$,) with a correction coefficient from the press calibration ($\propto = 0.22$). When immerged in water for 96 h the procedure includes the measure of vertical swelling of the surcharged, immerged test piece. The CBR value is computed by dividing the recorded load (at 2.5 and 5 mm penetration depths) by the relative standard load of a high quality crushed-stone materialI5.0 = $\frac{P_{5.5*\propto}}{20} * 100,$ $CBR = max\ \{ I_{2.5} , I_{5.0} \}$ (6).

$$I_{2.5} = \frac{P_{2.5*\propto}}{13,2} * 100 \qquad I_{5.0} = \frac{P_{5.5*\propto}}{20} * 100, \qquad CBR = max\ \{ I_{2.5} , I_{5.0} \} \qquad (6)$$

Mechanical

For cylindrical test tubes with a slenderness that is not $RcD,hRc16/32 = 0.64 + 1hD+D20$ (7), where D and h are respectively the diameter and height of the new test tube [41]:

$$\frac{Rc_{D,h}}{Rc_{16/32}} = 0.64 + \frac{1}{\frac{h}{D}+\frac{D}{20}} \qquad (7)$$

The 28 days compression strength and the tensile strengths can also be computed with the following formulas, at j days [42].

$$Rc28 = Rcj \times \frac{1.40+0.95j}{j} \qquad (8)$$

$$Rtj = 0.6 + 0.06 \times Rcj. \qquad (9)$$

C. *Results and discussion*

1) Physical characterisation :

It is observed that the maximum dry unit weight decreases with increasing percentage of pozzolana. This makes sense since pozzolana has a lower specific gravity than the sandy clay soil (**Table 7**).

The grading curve correction formula, as seen on Fig 2, gives the mid path between the maximum and minimum particle distributions, for the sub-base and base layers as prescribed by the CEBTP 1984 [1]. This formula is therefore a good reference for the calculation of litho-stabilisation proportions. The formula corresponds to the percentage composition SC/POU of 58/42.

Table 6 : Program tests of the geotechnical and mechanical characterisation of stabilised samples

Types of tests		Parameters sought	Norm
Geotechnical characterisation	CBR	Swelling potential when immerged CBR indices at 95% OPM	NF P 94-078 [29]]
Mechanical characterisation	Ultimate compression strength test (UCS)	7 days UCS 28 days UCS	NF P 94-077 [38]]
	Tensile strength (TS)	7 days TS 28 days TS	NF P 94-422 [39]

Table 7. Physical characteristics of the samples

property	PZ	SC	P1	P2	P3	P4	P5	CEBTP [1] Foundations	CEBTP [1] Base
Specific gravity	1.84	2.68	2.45	2.40	2.36	2.33	2.30		
Particle size	1/20	0/2	0/20	0/20	0/20	0/20	0/20	0/2 to 0/10	0/10 to 0/50
% at 80µm (*f*)	0.4	44.5	34.6	32.4	29.4	25	31.5	< 50	< 35
Cu	3.25	25	50	60	80	150		> 5	> 10
Cc	0.36	1.23	0.32	0.82	1.25	1.93	0.43	1<Cc<3	1<Cc<3
PI	-	41	31.5	29.2	28	25.3	24	< 30	< 25
$\gamma_{d\ OPM}$ (T/m^3)	-	1.93	1.90	1.87	1.79	1.75	1.69	1.9 to 2.1	> 2 T/m^3
w_{OPM} (%)	-	12.3	11.6	11.6	12.2	13.5	14.2	7 to 13	-

Swelling (%)	-	1.1	0.1	0.06	0.08	0.08	0.12	<2.5	<1
CBR Index	-	**23**	34	43	51	58	54	30	80

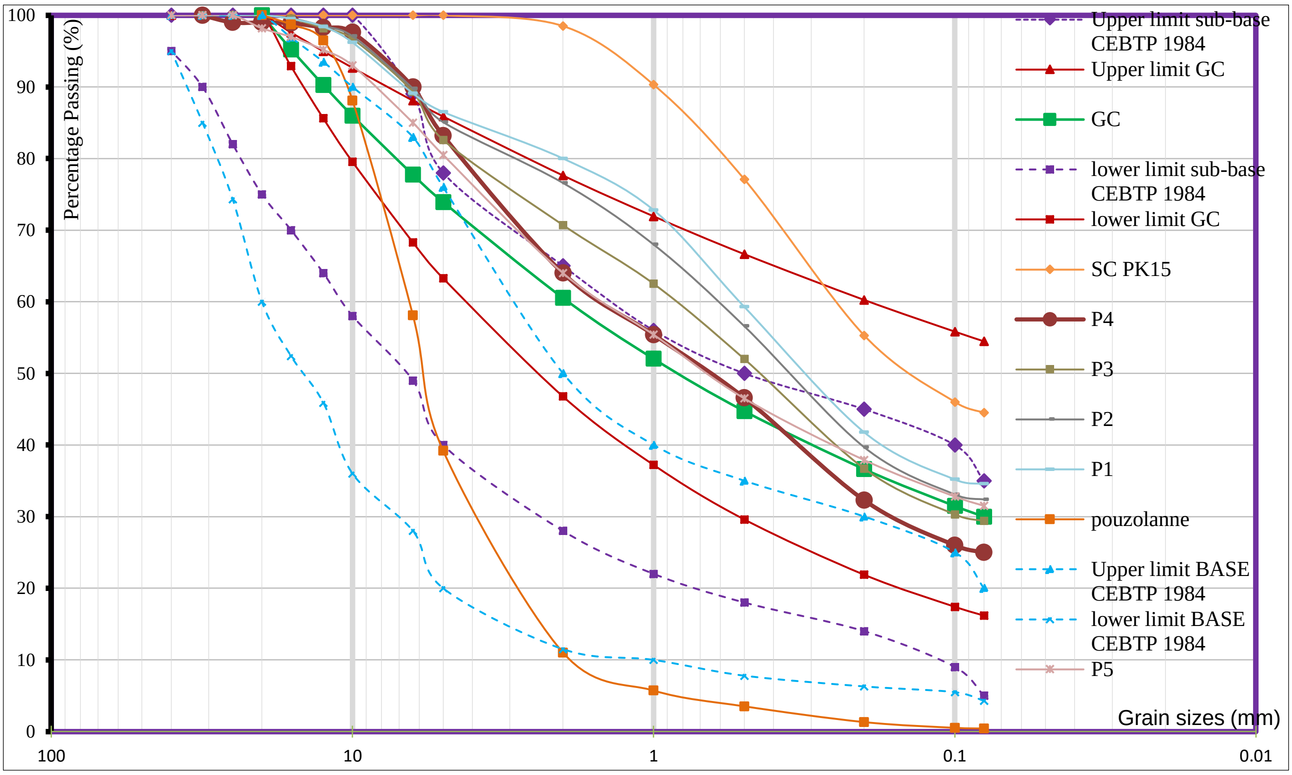

Fig 2 Evaluation of the grading curve correction formula, with SC soil, pozzolana, litho-stabilised samples (P1, P2, P3, P4 and P5), the upper and lower limit of grain distribution for sub-base layer and base layer

The sandy clay grain particle distribution does not comply because it does not fall within the grain size ranges. Based on the objective to maximize the host material (sandy clay soil), P5, P4, P3, P2 and P1 percentage compositions have been studied. Their grain size distributions are shown in Fig 2. It can be observed that all the curves enter the spindle except for particles between 6.3 and 16 mm which are above (contains lesser gravels) for the base layer. From the coefficient of curvature, the P4 (65/35) and P3 (70/30) samples are well-graded. The P2 (75/25) can be approximated to a well graded sample (see Fig 3).

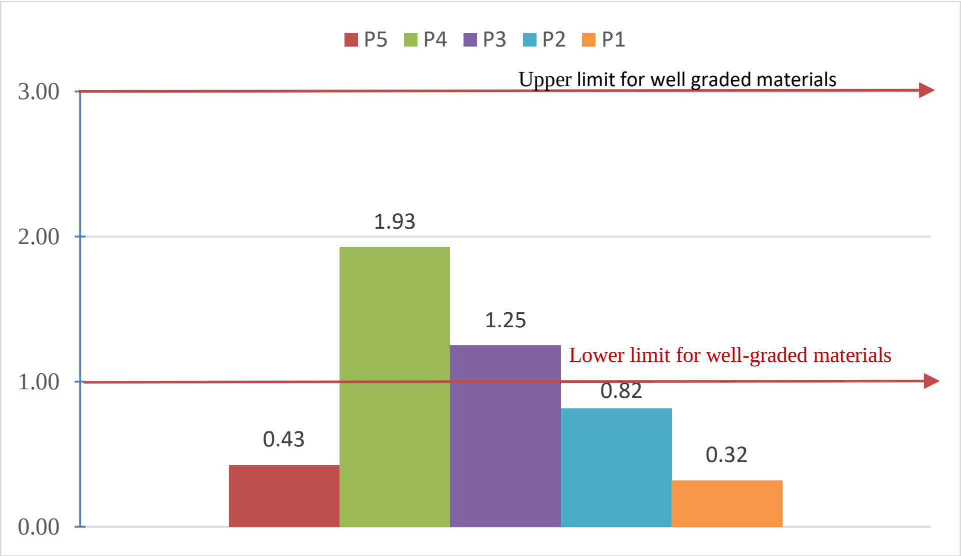

Fig 3. Coefficient of curvature of the litho-stabilised samples compared with the well-graded values

The sandy clayed soil is classified as a very plastic material, which is not compatible for sub-base and base layer. The lithostabilisation reduces the plastic index of SC (very plastic clays) to a medium plastic material. The new samples

Are compatible for sub-base layers of T2-T3 roads at P3 (70/30) and P2 (75/25) proportions. For T4-T5 sub-base and T2-T3 base layers, the P4 (65/35) and P5 (60/40) meet the specifications (see Fig 4).

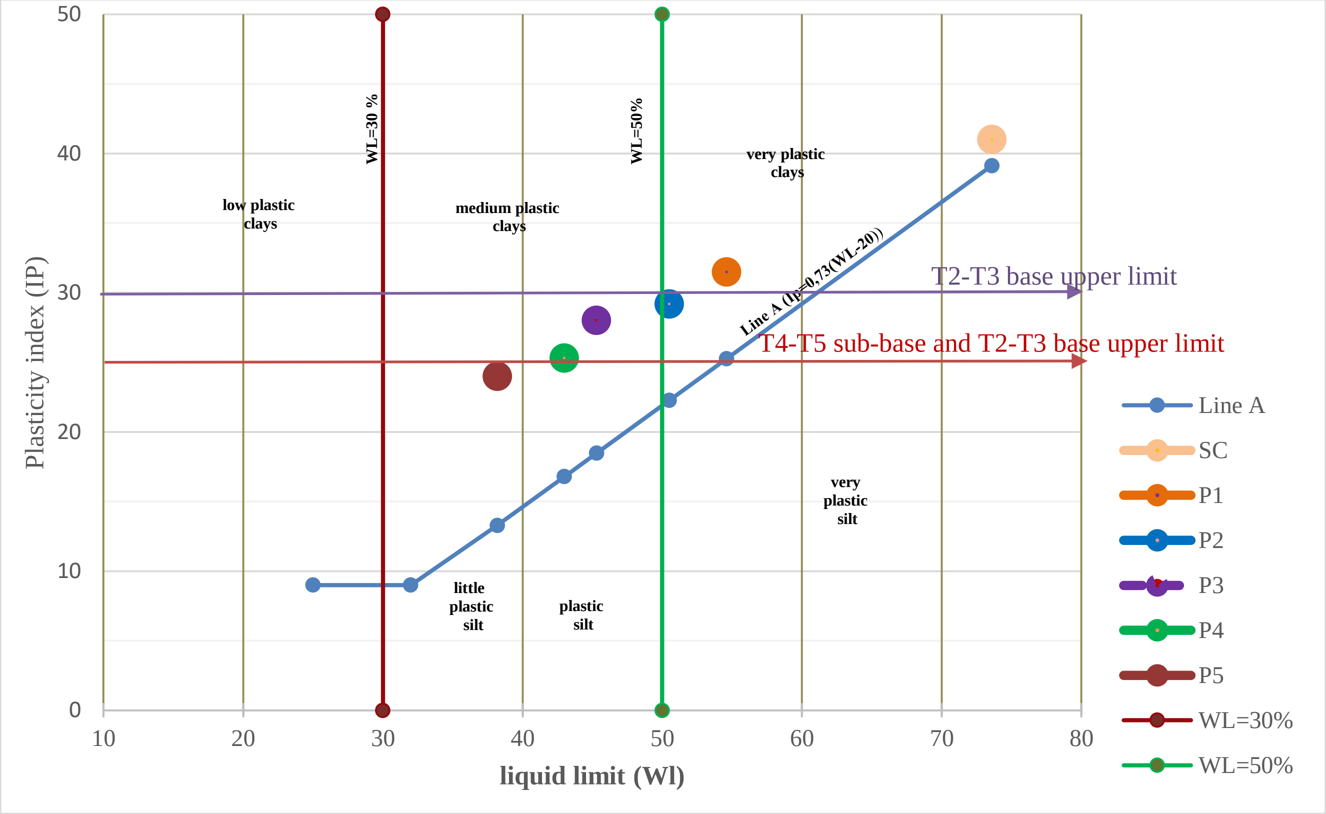

Fig 4. Position of studied materials in Casagrande diagram

2) Geotechnical characterisation

The Californian bearing ratios (CBR) results are shown in Fig 5. The natural host material does not have sufficient bearing capacity for sub-base and base layer in accordance to the CEBTP specifications. At 20% stabilisation with pozzolana, the material becomes useable for the sub-base layer of T2-T3 roads. The best mix for the T4-T5 and T2-T3 sub-base layer is the P2 (75/25). The CBR values rather decreases at 40% PZ. This is explained with the granulometric curves, which show that the material at 60/40 is no longer well graded. Well-graded soil materials can be easily compacted to dense deposits with high load bearing capacity [43]. To be used for base layer, the P4 can be stabilised with either cement or lime. It's CBR is 58 (<60), so it should be used at 98% of its optimum PROCTOR values.

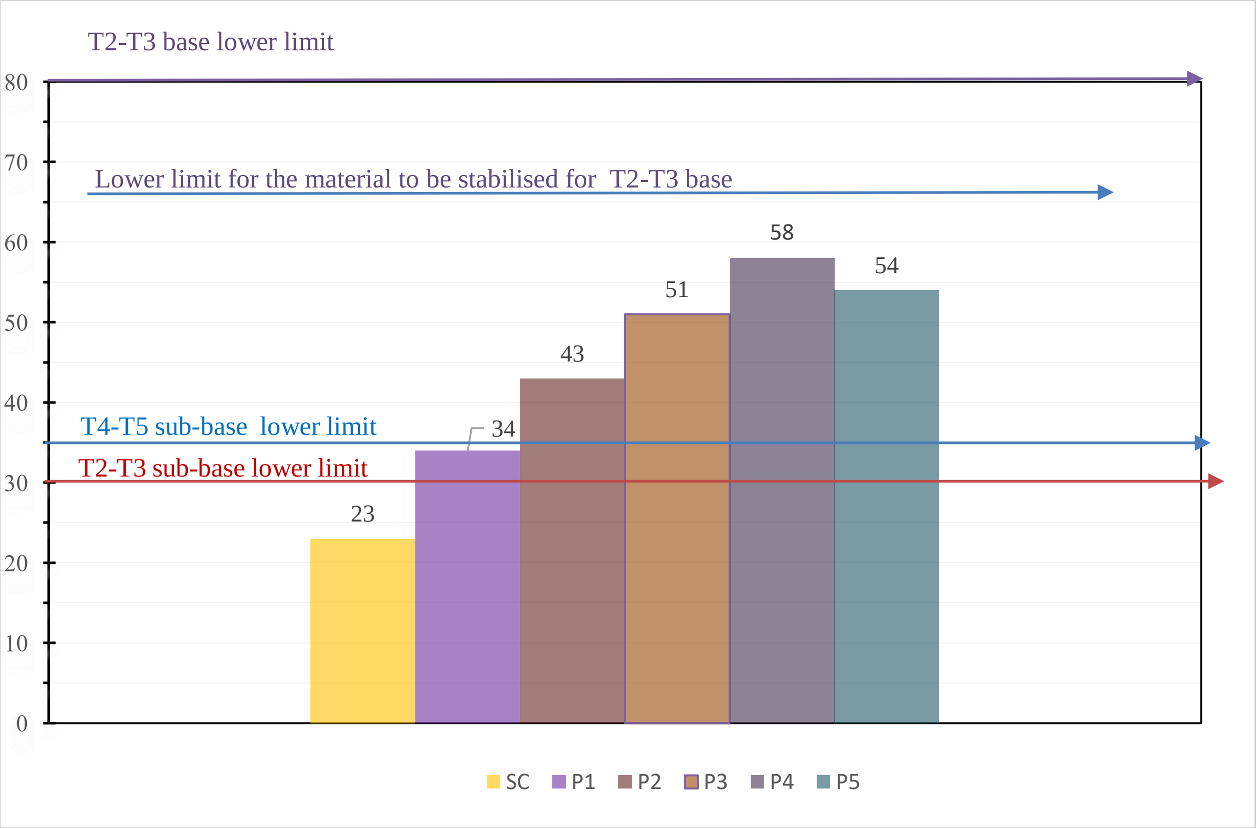

Fig 5. CBR results of the samples

3) Mechanical characterisation

In accordance to the CEBTP specifications, 7 days compressive strength of cement treated material is considered as reference to apprehend the stabilisation results. Interpretation of the results is mainly on the values of the test pieces cured in water (worse conditions), since road layers in coastal regions are exposed to immersion. There is a great drop in CTM strength from the cure in air to the cure in water. In addition to this, the Pa, Pb and Pc stabilised samples have lower strength when cured in street water than when treated in pipe borne water.

Pa (1%) is insufficient for the stabilisation of the sandy clay material. A maximum of 4% (Pc) dosage can be taken to design CTM with SC soil for T2-T3 sub-base and base layers, and T4-T5 sub base layers.

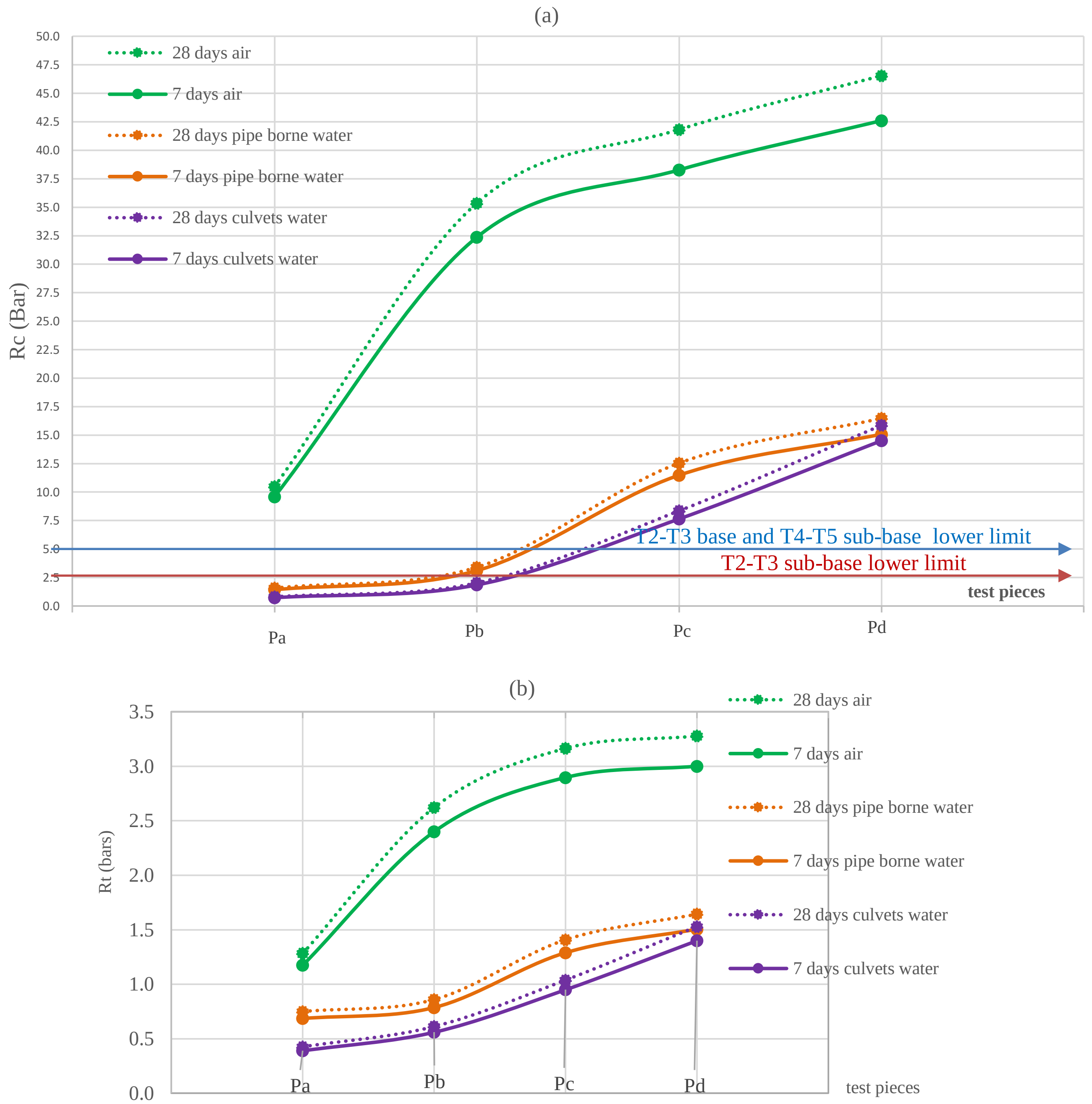

Fig 6 (a) Compressive strength, Rc; (b) Tensile strength, Rt

Compression and tensile strength results is the average of the strength from the three test pieces. As seen in Fig 6, the strength after 28 days cure and 7 days cure is approximately the same. This agrees with the CEBTP reference [1] that prescribes 7 days cure as a benchmark for testing cement-stabilised clay materials.

Curing conditions affect the final strength obtained from the treatment. When cured in the air, the strength is quite elevated compared to when the test pieces are immerged (Fig 6). This confirms that, for curing in worst conditions, the immerged curing benchmark should always be used for reference strength.

In addition to this, the chemical composition of the water used during the curing affects the strength of the cement treated specimen. With culvert water, the strength is always, for all the samples, less than the strength with pipe born water. The strength with pipe born water of the ‘Pb’ sample is greater than the recommended strength for T2-T3 sub-base. However, when cured in culvert water, the strength becomes lesser, making P2 it non-compliant.

The design of the mix should be such that the pore spaces of the coarser grains are effectively filled with the finer particles of the binders [44]. The degree of soil binding will ensure cohesion of the soil mix and thus maximum dry density.

D. CONCLUSION AND PERSPECTIVES

This paper focused on the assessment of improved sandy clay materials for road pavements in Cameroon with lithostabilisation and cement stabilisation. For lithostabilisation, 80/20 (P1), 75/25 (P2), 70/30 (P3), 65/35 (P4) and 60/40 (P5) mixed proportions with volcanic gravel (pozzolana) were appraised. For their physical identification, the specific gravity, particle size gradation, Atterberg limits, maximum dry density and optimum water content have been determined. With the geotechnical test (CBR test) the samples are appreciated for pavement layers. Furthermore, at optimum compaction, the cemented sandy clayed soil at 1% (Pa), 2% (Pb), 4% (Pc) and 6% (Pd) dosages were mechanically tested with the UCS test. Sample test pieces were gauged after curing during 3 days in the air (at room temperature of 25°C), then 3 in the air, 3 in pipe born water and 3 in culvert water for 4 more days.

The stability of the mixed soil increases with increasing strength of aggregates used (D>5mm), through properly designed and compacted mixtures (lithostabilisation). With this, the sandy clayed soil is transformed to a material whose physical properties matches with the range of materials prescribed by the CEBTP for sub-base and base layers. The plastic index is reduced (from 41 to less than 30). With its plastic index (29), its coefficient of curvature (0.8) and its CBR (43) results, the proportion 75/25 (P2) gives is an adequate material, for sub-base layer of T2-T3 and T4-T5 roads. The 65/35 (P4) mixed proportion at 98% of its maximum dry density is a correct material to be stabilised with a binder such as cement, for the base layer of the T2-T3 road.

On the other hand, a maximum cement dosage of 4% by dry mass can be considered for cement stabilisation of the studied sandy clay soil. The road layers are usually exposed to immersion, in environmental water with varying chemical composition that negatively affects the CTM. This makes the 2% dosage small, even for the T2-T3 sub-base layer.

Both methods can therefore be used to ameliorate the available sandy clay soil, for its use in the construction of various road layers. For further researches, the P3 and P4 will be stabilised with cement for the base layer. A close regard should be brought on the chemical impact of street water with X-rays fluorescence spectrometer analysis. Chlorine compounds can be experimented, to protect the cementing reactions.

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COMPETING INTEREST

The authors declare that they have no known competing financial interest or personal relationship that could have appeared to influence the work reported in this paper.

REFERENCES

1. CEBTP (1984) Guide Pratique de Dimensionnement des Chaussées pour les Pays Tropicaux; République francaise, ministère des relations extérieures, coopération et developpement: paris, France,; pp. 66-80.
2. SNH/UD (2005) Accessed on 19 May 2023 https://images.app.goo.gl/DVM51RbaABn9KhMAA.
3. Madjadoumbaye J, Ngapgeu F, Nouanga P, Abdou M, (2012) Improving the bearing capacity of laterite by adding sand. Electronic Journal of Geotechnical Engineering, Volume 12. pp. 23-32. http://doi/org/10.1080/12460125.2012.683318.
4. T. e. community, www.the engineering community. org, 20 November 2021. https://www.theengineering co,unity.org/what-is-soil-cement-advantages-and-disadvantages. Accessed on the 16 June 2023
5. Makusa G P, (2012) Soil stabilization methods and materials, A state of the art review. PHD student, Lulea university of technology: lulea, sweden.
6. Technology G R, Global Road Technology International Holdings (HK) Limited (2021) https://globalroadtechnology.com/what-is-soil-stabilization/. Accessed on the 16 June 2022
7. Behnood A (2018) Soil and clay stabilization with calcium and non-calcium-based additives. A state of the art review with challenges, approaches and techniques. Transportation Geotechnics, volume 17. pp. 14-32. http://doi/org/10.1016/j.trgeo.2018.08.002
8. Fred V (2020) Rapid degradation roads in Douala. Cameroun tribune. https://www.cameroon-tribune.cm/article.html/33809/fr.html/ rapid-degradation-of-roads-in-douala
9. Archibong A C (March 2020) A review of the principles and methods of soil stabilisation. International journal of advanced academic research sciences, technology and engineering, volume 6. pp. 89-115.
10. Patel A (2019) Soil stabilization. Geotechnical investigations and improvement of ground conditions, 1st ed. Elsevier Science Publishing. pp. 19-27.

11. Sherwood P (1993) Soil stabilization with cement and lime. State of art review. Transport Research Laboratory, HMSO. http://worldcat.prg/isbn/9780115511714
12. White D, Ceylan H, Rupnow T (2005) Fly ash soil stabilisationfor non uniform subgrade soils. IHRB Project , FHWA project 4 https://rosap.ntl.bts.gov/ view/dot/39495/dot_39495_DS1.pdf
13. G. P. H. l. d. T (2002) Actions sur les ponts, dues au trafic, EUROCODE 1-2, Partie 2; Comité Européen de Normalisation : Bruxelles.
14. Heba D (2019) Biocementation of soil by calcite / aragonite précipitation. Royal society of chemistry advances,.
15. Gaspar (1979) Chemical soil stabilization methods. Hungarian Road Research Institute.
16. Emmanuel J (2011) Utilisation de la technique de la litho stabilisation en assise de chaussée. Institut International D'ingénieurie de l'Eau et de l'Environnement: Ouaga, Ghana.
17. Arora K R (2011) Soil Mechanics & Foundation Engineering, 7th ed.; Delhi: Standard Publisher Distributors.
18. Patel A (2019) Soil stabilization. Geotechnical investigations and improvement of ground conditions, 1st ed.; Elsevier Science Publishing. pp. 19-27.
19. Sherwood P (1993) Soil stabilization with cement and lime. Transport research laboratory, HMSO. http://worldcat.prg/isbn/9780115511714
20. Olgum G, Asghar A, Baghini M, Akbar Firoozi A (2017) Fundamentals of soil stabilisation. International journal of Geo-Engineering, pp. 1-16. http://doi/org/10.1186/s40703-017-0064-9
21. Seco A, del Castillo J.M, Espuelas S, Marcelino S, Garcia B (October 2020) Sulfate soil stabilization with magnesium binders for road subgrade construction. International Journal of Pavement Engineering, volume 23. pp. 1840-1850. http://doi/org/10.1080/ 10298436.2020.1825711
22. Ghrici M, Belhireche H, Abdelghani Y, Harichane KH (2017) Effet du sable de dunes et de la chaux sur les proprietes geotechnique des sols argileux. Algerie equipements, volume 157. pp. 4-11.
23. Robert D. H, william D. k (1981) An introduction to geotechnical engineering. New Jersey: Prentice - Hall, Inc.
24. Craig R, (2004) Craig’s Soil Mechanics, 7th ed.; spon press; taylor and francis group: London and new york.
25. Dongmo K, Francois N, Alakeh M. N, Mbuh Moses Kuma (2020) Compressed stabilized earth bricks as building construction elements. IOSR Journal of Mechanical and Civil Engineering, vol. 17. pp. 42-48. http://doi/org/10.9790/1684-1704014248
26. Choo B. S, Newman J (2003) Advanced concrete technology, constituent materials. Burlington: Elsevier. http://doi/org/10.1016/B978-0-7506-5686-3.X5246-X
27. Linda L. D, Nguimeya N. G. A, Arlin B. T, Ndigui B, Elie K, Elsa Q, Thamer S. A et Thomas A. B (15 june 2021) Engineering and Mineralogical Properties of Portland Cement Used for Building and Road Construction in Cameroon. Springer. http://doi/org/10.1007/s42947-021-00055-9
28. TIKO A (2011) Etude de lithostabilisation de la terre de barre avec du concassé: vers la recherche d'un nouveau matériau utilisable en assise de chaussées revêtues. Université d'ABOMEY-CALAVI (EPAC), Dahomey.
29. AFNOR (1997) Indice CBR après immersion - Indice CBR immédiat - Indice portant immédiat. AFNOR, Paris.
30. AMBA D. J. C (2021) Reaction chimiques endogenes des materiaux cimentaires, Douala: Laboratoire E3M, ENSPD.
31. AFNOR (1996) Determination de la teneur en eau pondérale des matériaux, méthode de la dessication au four à micro-ondes. AFNOR, paris.
32. AFNOR (1991) Détermination de la masse volumique des particules solides des sols, méthode au pycnomètre à eau. AFNOR, paris.
33. AFNOR (1996) Analyse granulométrique par tamisage à sec après lavage. AFNOR, Paris.
34. AFNOR (1999) Détermination des références de compactage d'un matériau, essai proctor normal - essai proctor modifié. AFNOR, Paris.
35. AFNOR (1993) Détermination des limites d'atterberg, limites de liqudité à la coupelle-limite de plasticité au rouleau. AFNOR, Paris.
36. Emiliano P. P (2016) Road Infrastructures Design lecture 2 - soil, Yaounde: National Advanced School Public Works.
37. Iqbal S «Define Civil» 16 May 2021. https//definecivil.com/atterberg-limits. (accessed on 19 May 2022)

38. AFNOR (1997) Essai de compression uniaxiale. AFNOR, Paris.
39. AFNOR (2001) Détermination de la résistance à la traction; méthode indirecte - essai brésilien. AFNOR, Paris.
40. Transport Research Laboratory. TRL (January, 1999) Guidelines on the Selection and Use of Road Construction Materials, department for international development. https://www.semanticscholar.org/paper/guidelines-on-the-Selection-and-Use-of-Road-Trl/de8182449a43070ebef7c6d0dcd9fc450e491c61
41. IFSTTAR (2017) Evaluation de la resistance du beton insitu. *les collection d'IFSTTAR*, Vols. 1-7, p. 2.
42. Yazid A (2005/2006) Béton précontraint. BECHAR: Centre Universitaire de Bechar.
43. Lérau J (2005-2006) GEOTECHNIQUE 1, Cours - Chapitre 1, Toulouse: Institut national des sciences appliquees de Toulouse.
44. Archibong G, Sunday E. U, Akudike J, Okeke O (March 2020) A review of the principles and methods of soil stabilisation. *International Journal of Advanced Academic Research | Sciences, Technology and Engineering | ISSN: 2488-9849*, Vol. 6, Issue 3. pp. 89-115. https://www.researchgate.net/publication/342448451_a_review_of_the_principles_ and_methods_of_soil_stabilisation