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Research Article

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Geotechnical properties of clay soil in Mouyondzi in Congo treated at cement and fine fractions of lateritic to improve the performances of blocs of earth: An approach based on the multi-criteria assessing

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Abstract The acceleration of climate change and the continuous increase in the world's population require technical improvements in earth building. Thus, the local treatment of soils necessary for earthen construction is of great importance. This paper presents the partial results on the assessment of the geotechnical properties of Mouyondzi clay soils, treated at 2%, 3%, 4%, 5% of cement content; then 10%, 20%, 30% of fine lateritic fraction to confection the improved earthen blocks. The effect of these additions of cement and fine lateritic fraction consists in enhances the durability of earthen buildings during the exploitation. The multi-criteria evaluation method proposed and based on measured geotechnical parameters (granulometry, Atterberg Limits, Compressibility index…) allowed analyzing all the possibilities of material selection. The first results obtained show that the studied mixtures of soil have the accepted properties to manufacture different type of earth blocks (Adobe, BTC).

Keywords Earth bloc, Plasticity index of soil, Durability of earth building, Multi-criteria evaluation

Introduction

The earthen buildings represent a traditional construction mode in world, with of interest performances (e.g., physical or mechanical stability) in relation ecological, climatically and economic conditions [1-2]. The used earth is a local material and recyclable that offers a good workability, a wide variety of construction types with low construction, maintenance and environmental impact costs [3-4]. But in tropical regions (case of countries in developing), despite the various studies on building land [5-7], some buildings are constantly confronted with early deterioration and the resulting durability problems (penetration of water, loss of material…) [8]. The defects on earthen constructions in Mouyondzi at Congo (Adobe building, Cob, Compressed earth brick…) due to the effect of rainwater, humidity variation, and insufficient of maintenance illustrate the above propos. The method of improvement of earthen buildings must permit to consider the actual factors of their deterioration in relation with the ecological conditions, climatic, economic and demographic [9, 10]. To ensure the durability of earthen building, the improvement of local soil properties by the addition of sand or cement as stabilizing element has already been proposed in various publications [6]. However, the appropriate proportions of the mixtures are not defined in the available publications. The proportion of soil may be influenced by the mineralogy nature and granulometric distribution of soils particles [11]. In this condition, the selection of the appropriate mixtures of materials requires several geotechnical analyses and an expert support. The Mouyondzi locality has a large earth deposit, notably the clay, lateritic soils and sand traditionally exploited without prior geotechnical study. This study would be an asset for an appropriate use of materials in order to reduce the costs of the environmental impact of the construction or maintenance of building [12]. The clay soils which represent the base material used in the confection of earthen blocs are characterized by their particular plasticity and their sensibility in presence water [13].The hydraulic binder (cement) treatment of clay soils neutralize the plastic fines to reduces their plasticity index responsible for swelling or shrinkage by reduction the clay and silt content of soil [14]. Indeed various parameters such as, the plasticity (consistence of soil), grain size, compressibility (compactness), are generally used to identified and classifier the soil in function of the type of construction (earth bloc) [5, 11]. Despite a large research's on the geotechnical characterization of soil for the confection of earth blocs, to our knowledge, the multi-criteria assessment of geotechnical properties of soils has not yet proposed. For example, the relationships between plasticity and grain size of treated soil on the one hand, and binder content on the other are rarely modeled. While the simultaneous consideration of various soils characteristic when choosing of the material mixtures is one of the challenges for the analyses in geotechnical engineering. In that, the lack of general methodology for this multi criteria description is a scientific lock and prevents in-depth studies in the field of earthen buildings.

The aim of this work is to characterize the geotechnical properties of mixtures soils from the localities of Mouyondzi treated in cement and with the fines fraction of lateritic soil for their valorization in confection the improved earth blocs. An assessment multi-criteria approach associate the knowledge of experts and existing methods is proposed to realize this study [15, 16]. The original contribution of this such holistic approach for assessment compared to existing works is that considers a large number of simultaneous criteria, in order to fill related at the selection of the materials of earth constructions. The geotechnical properties of the raw clay soils are analyzed first to best compare the effect of introducing of small doses of cement and the fine lateritic fraction [5, 17]. This analyzes focuses on four mains parameters, which are granularity, plasticity, wettability, compressibility respectively, for which partial results are discussed.

Materials and Methods

Used soils

The studied soils (clay and lateritic) were collected on 0, 3 - 2, 0 m in the deposits exploited by the population in urban area and locality of Mouyondzi. In each quarry, soil samples were collected after an observation of noting significant difference in the color and texture of the soil used (Fig.1). The used cement is a production of Dangote S.A of type 32.5 available on the market in Congo.

(a) (b)

Figure 1: Samples of lateritic collected in quarry of Mouyondzi, (a) clay soil, (b) lateritic soil

Analyzed soils mixtures

The physical (addition of fines lateritic fraction content) and chemical (addition of cement content) treatment applied on the clay soil applied has permitted to obtained different mixtures (see Table 1) [18]. The proportions of the constituents of different combinations are expressed as a percentage by mass to the solid mass from equation 1 [19]:

$$P_m = \frac{P_M * T_m}{100} \quad (1)$$

P_M- weight of the mixture, Tm-material rate, Pm- calculated weight of material.

For each mixture, P_M is the summation of weight of all dry materials (see equation2):

$P_M = P_S + P_{La}$(2)

P_S - weight of clay soil, P_{La} - weight of lateritic soil.

For more details on the calculus of weight of mixtures and their water content, the reader can consult the work of Rigassi (CREA-Terre 1995)[18].

The obtained percentages form these formulas were adjusted by expertise and review publications. We considered that the soils constituting a mixture must have a granularity $D_{max} \leq 10$ mm as reported by Delgado et al. [13].

Table 1: Composition of different mixtures

Code	Material		
	clay soil	**Lateritic soil**	**cement**
A	100%, 98%,97%,96%,95%	0%	2%,3%,4%,5%
B	100%,90%, 80%,70%	10%,20%,30%	0%

Applied Tests and Adopted Methodology

The tests of soils identification are realized on each collected sample for their geotechnical classification: The granularity is determined by granulometric test, which defines the distribution of grains according to their size (see standard NF EN 933-1 [20], NF P94-057 [21]). The clay soils were sieved with a 4mm sieve, and the lateritic with a 6.3 mm sieve after a preliminary screening. The plasticity of soils is estimate by Atterberg Limits test, which determine the transitions between different states of the material with respect to the water content (liquidity limit LL, plasticity limit PL, plasticity index PI), as define the standard NF P 94-051[22]. IP index is a difference between LL and PL, PI = LL-PL. The compressibility of soils mixtures were estimated by the modified Proctor test (standard NF P94-093) [23], to determine the maximum dry density and the optimum water content necessary for compactly of material. The employability zonal of soils are define (graphic) to identifying each type of earth construction to according the study soil or mixture [6, 11]. The cleanliness of the soils was estimated by the methylene blue test (VBS), to check the organic matter content (see standard NF EN 933-9 [24]). In this order, the adopted scientific method consists in four steps as explicated by Figure 2. The modeling of geotechnical properties is realized in OriginPro software, which offers different possibility torepresents and unify the data [25].

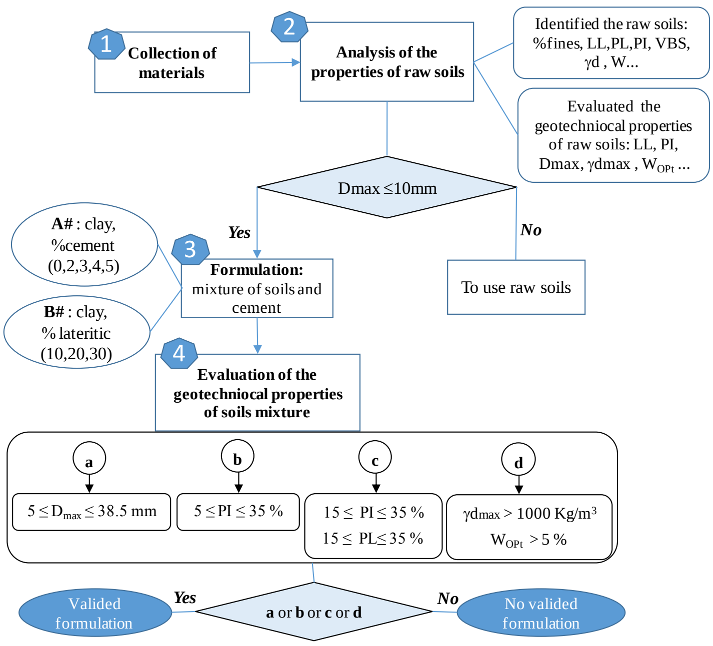

Figure 2: Method for multi criteria assessing of geotechnical properties of soils mixtures to qualify their uses in earth buildings.

Results & Discussion

Geotechnical properties of raw soils

The Table 2 presents the geotechnical properties of tree raw soils (granularity, plasticity index, Methylene blue value, Modified Proctor parameters).It is observed in Table 2 that major elements of all three studied samples are the fine soils (% sieves at screen 80µm > 35%) to regard the standard NF P 11-300 [26].The plasticity index PI between 25% at 40% classify both samples 1# and 2# as clay soils. Moreover compared to Casagrande diagram [22], the mineral clay of medium plasticity and the organic clay and silt of high compressibility are identified as geotechnical classes of these soils. The blue value indicates that these soils are sensitive to water and what needs to be treated. The clay presents an acceptable property for fabrication of bricks to regarding the wettability criteria; but the lateritic soil is qualified for pottery. The lateritic must in this case used as an additive to enhance the properties of clay soil for the sustainability of earthen buildings.

Table 2: Summary of geotechnical tests on raw soils

Sample /material	Sieve at screen 80 µm (%)	Atterberg Limits (%)			Methylene blue value (VBS)	Proctor	
		LL	LP	PI		$W_{opt\ (\%)}$	ρ_{max} (g/cm3)
1# Clay	80,90	46,40	18,33	28,07	0,33	31	14,04
2# Lateritic	75,40	68,00	39,50	28,50	2,15	23	16,40

Geotechnical characteristics of soils mixtures

Plasticity and granularity of raw soils and mixtures

Figure 3 shows the variation of plasticity index of raw clay and the mixtures at 2%, 3%, 4% and 5% of cement content. Figure 4 gives the variation of plasticity index in relationship of fine fraction of the clay soil content.

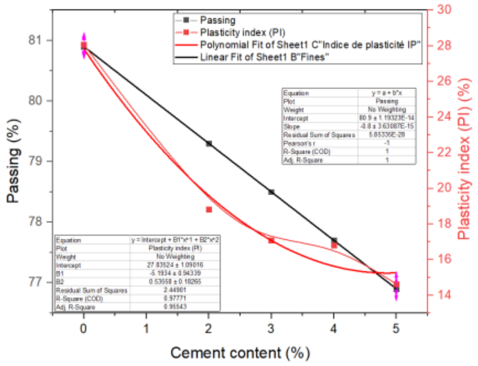

Figure 3: Variation of plasticity index of raw clay and the mixtures at 2%, 3%, 4% and 5% of cement content.

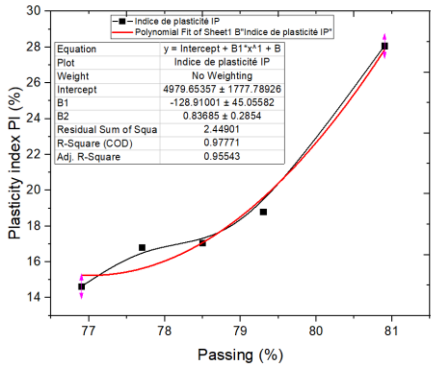

Figure 4: Variation of plasticity index in relationship of fine fraction of the clay soil content.

The addition of cement leads to an increase in the liquidity limit of the clay soil due to the cementation action at 2%, 3% and 4% of binder content (cement), were the values of LL are 52, 8%; 52,40%; 52,07%. The cement content of 2% corresponding to the peak (high point) of the curve with a plasticity index (PI) value of 18, 81%. But at 5% the decrease of liquidity limit is observed (LL value of 51%) and a plasticity index (PI) of 14, 63%

value. The fines and plasticity index are highly correlated and decrease at the same time (Figures 3,4). The table 3 provides the summary of theses values.

Table 3: Atterberg limit, optimal water content and maximum dry density of the mixture of clay with cement

Cement content	LL (%)	PL (%)	PI (%)	γ_d (t/m^3)	W_{OPM} (%)	Fines %
0%	46.40	18.33	28.07	1.404	31.00	80.90
2 %	52.80	33.99	18.81	1.415	30.94	79.30
3%	52.71	35.64	17.07	1.466	28.60	78.50
4 %	52.49	35.68	16.81	1.479	28.8	77.70
5 %	51.60	36.97	14.63	1.457	29.30	76.90

Further, the addition of lateritic fines to the clay soil mass shows that the mixture tends to absorb more water, causing a slight decrease in its plasticity index value from 25% to 26%. Figures 5 and 6 provide the variation of plasticity index of clay mixtures with 10%, 20%, 30% of fines fraction of lateritic.

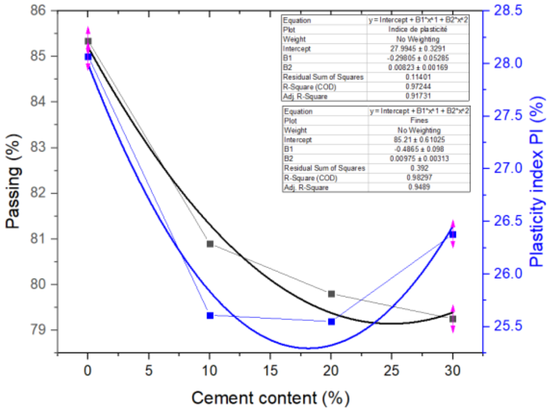

Figure 5: Variation of plasticity index of clay mixtures with 10%, 20%, 30% of fines fraction of lateritic.

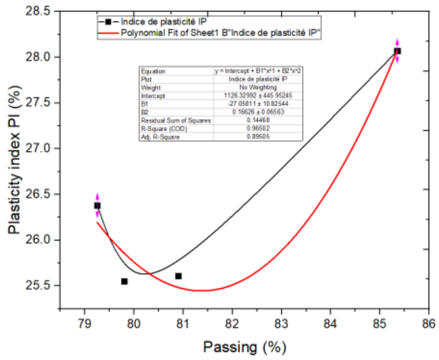

Figure 6: Correlation between plasticity index of clay mixture with 10%, 20%, 30% of fines fraction of lateritic.

The Table 4 gives the summary of parameters values on the Figures 5 and 6.

Table 4: Atterberg limit, optimal water content and maximum dry density of the mixture of clay and lateritic

Lateritic content	LL (%)	PL (%)	PI (%)	γ_d (t/m^3)	W_{OPM} (%)	% fines
0 %	46.40	18.33	28.07	1.404	31.00	80.90
10 %	56.50	30.89	25.61	1.426	31.90	80.35
20 %	56.20	30.65	25.55	1.462	30.40	79.80
30 %	56.75	30.37	*26.38*	1.496	29.50	79.25

To regarding the wettability criteria, the addition of cement or the fine fraction of lateritic in the clay modifies its initial consistency then qualifying it for pottery (Figure 7).

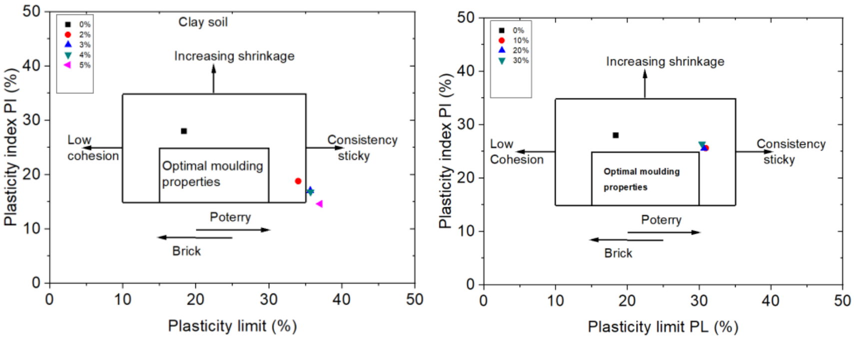

Figure 7: Casagrande diagram modeling the wettability property in correlation of Atterberg limits parameters, (a) treated clay with 2%, 3%, 4%, 5% of cement, (b) treated clay with 10%, 20%, 30% of lateritic.

To regarding the obtained results in relation to plasticity parameter, the clay soil not improvement is appropriate only the fabrication of adobe (Figure 8). Furthermore, the mixtures of clay soil with cement have plasticity suitable for bricks [11], (a) adobe, rammed earth, BTC with 2% of cement content, (b) adobe, BTC with 3, 4, and 5% of cement content.

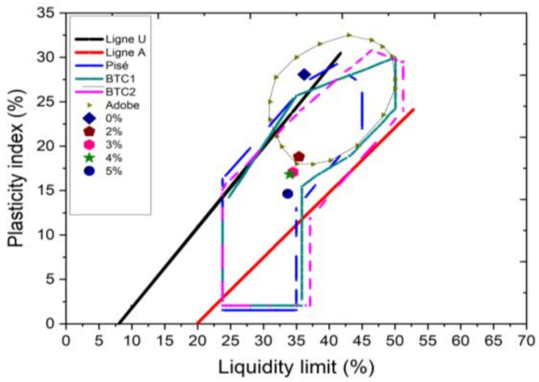

Figure 8: Plasticity nomograms of clay treated at cement determining the earth building type in relation of recommended areas of PI/LL of soils in the publications [11, 28] for adobe, compressed earth blocks or rammed earth, BTC 1 corresponding at CEB 1 [11]; BTC 2 is a CEB 2; pisé is a rammed earth [27].

The Figure 9 following the plasticity nomograms of the stabilization of clay with the fraction fines of lateritic soil. Based on the recommended areas of PI/LL of soils, the improvement of clay soil at 10% and 20% of lateritic fraction fines content is required for adobe and BTC 1 bricks. At 30% of lateritic fraction fines content, the mixture is appropriate only the adobes bricks.

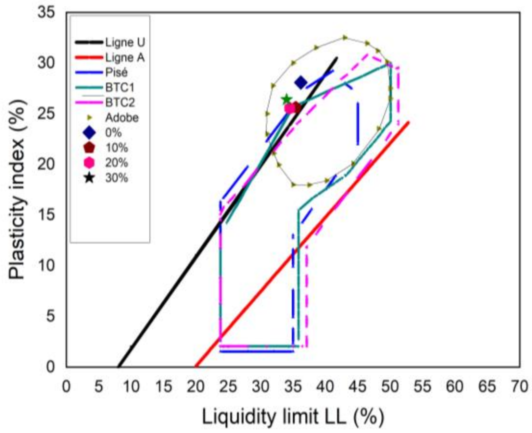

Figure 9: Plasticity nomograms of clay improved at lateritic fraction fines determining the earth building type in relation of recommended areas of PI/LL of soils [6,11] for adobe, compressed earth blocks or rammed earth.

Compressibility of raw soils and mixtures

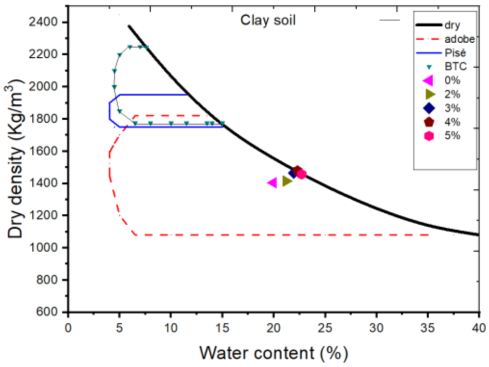

Figure 10: Compaction nomograms, dry density in relation of optimal water content of treated clay at 2%, 3%, 4%, 5% of cement content and recommended areas for adobe, rammed earth and compressed earth blocks.

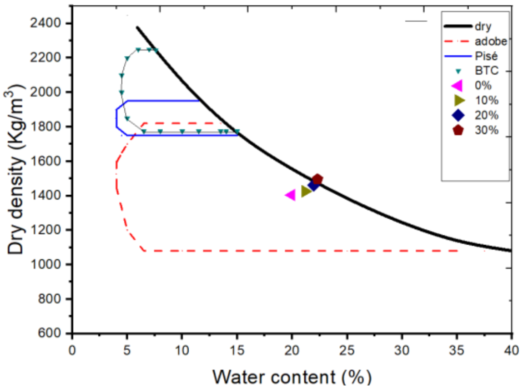

Figure 11: Compaction nomograms, dry density in relation of optimal water content of treated clay at 10%, 20%, 30% of fraction fines of lateritic and recommended areas for adobe, rammed earth and compressed earth

Contrary at tests of plasticity and analysis of granulometry which allowed the definition of three types of improved earth bricks, the partial result of compaction test «Modified Proctor» (Figures 10, 11) indicate that these two mixtures is adapted only for the adobes. This result can be explained by the fact that the realized compaction test is less recommended for coherent soils. The realization of a static compaction test as recommended in publications [28] must permit to confirm or not this result.

Conclusion

This work focused on the multi-criteria evaluation of treated clay soil samples form the Mouyondzi localities for their qualification as sustainable earthen building materials. A sample of clay soil treated with 2 and 5 cement content; and another sample of the same soil improved with 10%, 20% and 30% of fine lateritic fraction were analyzed according to actual standards. The partial results obtained show that:

- the areas soil of Mouyondzi is classified as a clay soil with low plasticity; and the used lateritic as a very plastic clay-silt soil (see H.R.B; U.S.C.S construction standards)[11].
- the clay soil mixture at 2% of cement content is suitable for the manufacture of earth blocs (Adobe, rammed earth, BTC) from the point of view of plasticity. The mixtures at 3%, 4%and 5% of cement content are only suitable for Adobes and BTC (plasticity criteria).
- Clay soil improved with 10%, 20% of the fine lateritic fraction can be used to make Adobes and BTC 1 blocks with respect to the plasticity requirement. The treatment with 30% of the fine lateritic fraction is only suitable for Adobes.
- the maximum dry density values obtained by the modified Proctor test on the two samples quality the mixtures only for Adobes. A static compaction test as recommended in standards for cohesive soils should be carried out to confirm this analyze or not.

The mixtures of clay at 2% of cement content, and clay soil at 10% and 20% of fine lateritic fraction are more optimal form the economic point of view and in terms of satisfaction the technical requirement (plasticity and grain size). For their final qualification, additional tests must be carried out to analyze their behavior at depth. These tests could concern the sedimentometry of these soils, the organic matter content, the static compaction (Proctor, CBR), the static compressive strength, the water absorption, the erosion ability of the material, and the drying kinetics of the material.

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