The Use of Weathered Ignimbrites for the Production of Stabilized Earth Blocks (Seb): Case of Dschang (Western Cameroon)

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Abstract— *The weathered mantle developed on welded ignimbritic formations of Dschang (Western Cameroon) constitute for population living in the vicinity, the raw material use to manufacture building blocks. However, many defects have been noticed on houses built using these blocks such as cracking, swelling and low compressive resistance of blocks.*

The purpose of this study is to investigate the physical and geotechnical properties of these soil materials and their suitability in manufacturing Stabilized Earth Blocks (SEB) for optimized local constructions by testing their physico-mechanical characteristics. Results of these investigations, reveal two major types of soil profiles: the soil profile from top hill (Meka'a Profile) and the soil profile of downhill (Mingou Profile). These soil profiles are well-developed with three main horizons (A, B and C). The surrounding population has been using materials from B horizons (middle unit of soil profiles) for the manufacture of SEB. These materials are mainly composed of quartz (12 – 31%), goethite (17 – 22%), kaolinite (8 –18%) and gibbsite (23 – 44%). They display high value of moisture content (48 – 61%) and are very porous (47%). Grain size analysis classified these materials as fine-grained particles (47 – 65%) and so do other geotechnical classifications systems such as HRB, GTR and LCPC. The Atterberg limits reveal that they have high plasticity in nature with plasticity index ranges from 39 to 53.8%.

Satisfactory results were obtained when the weathered materials was stabilized with cement (CPJ 35) above 6%. Flexural strength tests ranged from 2.11 – 2.44 MPa and compressive strength ranged from 2.68 – 3.53 MPa. Nevertheless, some corrections are necessary to enhance these characteristics. This can be carried out by grain size distribution correction or the use of any type of chemical stabilizer.

However, some more detailed specific tests are still required in a bid to optimize the suitability of weathered ignimbrites for stabilized earth blocks production.

Keywords*— *Ignimbrites-Local materials-Geotechnical classification-SEB-Valorization

I. INTRODUCTION

Southwestern area of Mt Bambouto has been subjected to several volcanic episodes. Those episodes have respectively laid: basalts (21 Myrs), ignimbrites and trachytes (18.5 - 15.3 Myrs), phonolites (15 – 4.5 Myrs) and pyroclastic dejections (0.5 Myrs) (Kagou et *al*., 2010).

Ignimbrites (17%) represent the major volcanic rocks of Mt Bambouto. The outcrop of ignimbrites covers an area of about 135 km^2 (Tchoua, 1968; 1974) where they are underlaid by granitic basement at Dschang area. They crop out around localities of *Menouet*, *Makong II* and *Tsintsé*. They are mainly composed of acidic minerals (Youmen, 1994; Gountie Dedzo, 1994; Gountie Dedzo et *al*., 2011).

Once exposed to the atmosphere, those rocks undergo some physical and chemical weathering. Because of the prevailing equatorial climatic conditions, they encounter a high degree of weathering, and the weathered products are used for several applications (agriculture, civil engineering, ceramics and others).

These loose materials after being been classified in terms of their suitability for civil engineering works through GTR (A_4 and A_1), HRB (A-6 and A-7-5) and LCPC (silty fine sands), have been found to be inappropriate for civil engineering works due of their high water content and predominance of fine particles (Poueme Djueyep, 2012). Due to the rapid rate of urbanization, the consequence is the rapid rate of erecting building. But, with the low purchasing power, the acquisition of modern construction materials (cement, concrete, gravel, sand…) is not really affordable to a major segment of the population. That is why the local population have to turn to local materials: weathered materials developed on ignimbrites. It has been discovered that sandy materials quarried at the surroundings have been found to be of poor quality when used for construction (Tchop, 2000; Ananbe Njitsop, 2008; Fobeu Nguemo, 2011). Also, because of the socio-political prescription encouraging the use of local resources found within the vicinity of any locality for its development. With this scenario in place, this also raises with some environmental concerns.

More so, it has been observed that houses built with these materials displayed some inconveniences such as cracking, swelling and poor resistance of blocks. Previous studies by Tematio (2005) and Ananfouet Djeufack (2012) have characterized these materials as 'fine laterites'. Soils of similar characteristics located in Odza (Centre Cameroon) have been used to produce SEB of appropriate quality (Dtawagap Doumtsop, 2005). However, there is still an important need of scientific information concerning the case of Dschang and particularly, its outcrop of ignimbrite. The objective of this paper is in a bid to fill the gap of the existing documentation on the use of local construction materials in Cameroon.

The highlight is to set out the roles played by the clay mineralogy in the behavior of stabilized earth blocks.

II. DESCRIPTION OF THE STUDY AREA

The study area covers a surface of about $9km^2$ (Tchoua, 1968; 1974, Youmen et *al.*, 2005) and is found in Dschang Subdivision of Menoua Division of the West Region of Cameroon. It is located from 5°25′51″ and 5°27′ of Northing and 10°01′13″ and 10°03′17″ of Easting (Fig. 1) the ignimbrite outcrop is overlaid by an aphyritic basalt (Nkouathio et *al*., 2008) which is undergoing a "black-lateritic" alteration (Tchoua, 1968).

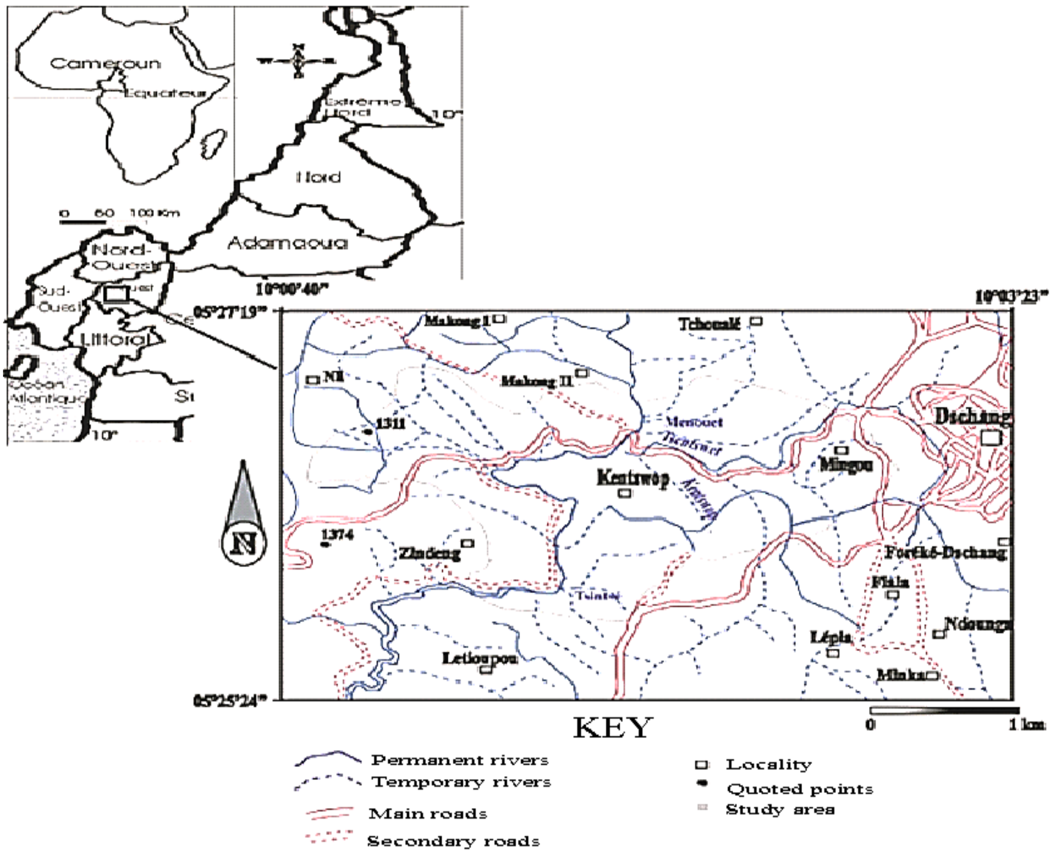

FIGURE 1: LOCATION MAP OF THE STUDY AREA (EXTRACTED FROM BAFOUSSAM MAP 1C -1/50.000 AND MODIFIED BY GOUNTIE DEDZO (2004)

The site of study represents the weathered mantle developed on volcanic rocks. It covers neighborhoods such as Mingou, Tchoualé, Meka'a, Kentswop and "Dschang-main town". It displays a height of about 80 m from the main river *Tsentwet*. The entire area lies within the "Highlands" of West Cameroon.

The outcrop (fig. 2) is surrounded by basalts, phonolites and ignimbritic tuffs (Gountie Dedzo, 2004; 2011), and it is also underlaid by granito-gneissic formations as described by Kwekam (2005).

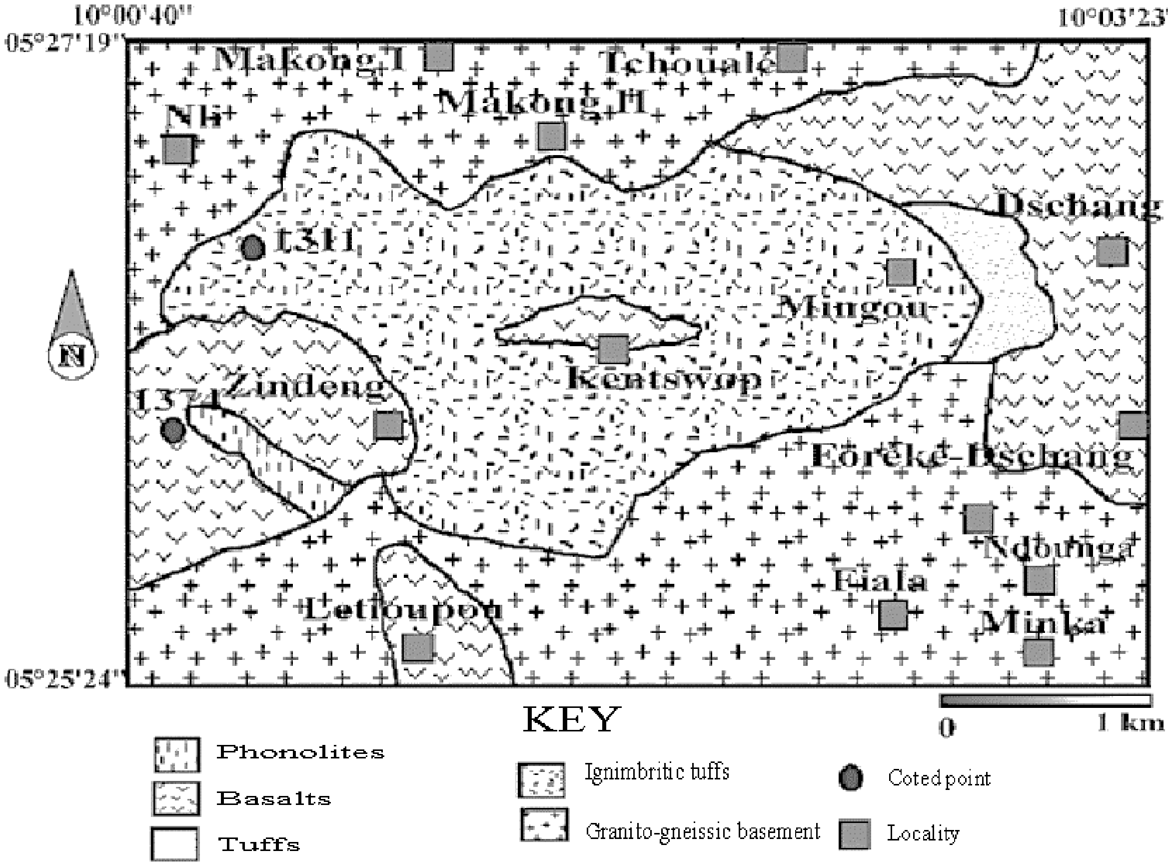

FIGURE 2: GEOLOGICAL MAP OF THE STUDY AREA: GOUNTIE DEDZO (2004)

III. MATERIALS AND METHODOLOGY

With the help of maps and the GPS, the study area was well demarcated and the positions of trial pits and trenches were established. The sampled materials consist of lateritic soils from horizons which have already been used by the local population for bricks production (EM-1 and EM-2). Analysis were carried out on these specimens at the Local Materials Promotion Authority (MIPROMALO) in Yaoundé. Tests carried out included, mineralogy, grain size analysis, consistency of clays, specific gravity, moisture content and porosity. Other tests performed on the earth blocks include water absorption rate test, as well as the flexural and compressive tests.

3.1. Mineralogical Analyses

The mineralogical composition of the materials was studied using an X-ray diffractometer. The samples were first heated at 105ºC for 24 hours before being crushed to powder of 80µm diameter using a porcelain mortar. The apparatus used, was BRUKER-type diffractometer, operating through the reflection of Kα2 copper rays. The scanned angular domain was $5^\circ \leq 2\theta \leq 90^\circ$ with an angular space value of 0.020º, within few seconds and at an ambient temperature of 25ºC. The apparatus was connected to a computer which provided automatically the diffractograms. The different peaks of the diffractograms were determined with the aid of data automatically furnished by the Diffrac+software and ASTM boards.

3.2. Geotechnical Analyses

There are two separate procedures for obtaining the grain size distribution of soils: sieve analysis (by the Norm NF P18-560) for particles of a diameter of above 80µm and sedimentation analysis (by the Norm NF P14-057) for particles of a diameter of less than 80µm.

Atterberg limits were used to determine the plasticity index of the studied materials. The liquid limits were determined using the Casagrande apparatus while plastic limits were determined according to the NF P94-051 standard.

IV. RESULTS

4.1 Morphostructural description of soil profiles

4.1.1 Downhill profile P1 (profile of Mingou-Nzong)

This profile has been described from a trench located at 10°02′26″ Easting and 05°26′17″ Northing (fig. 3) found at a down side of a slope. This soil profile is mainly composed of three units: lower unit, middle unit and upper unit:

- **Lower unit**

This unit is massive in its structure, and is characterized by a thick weathered layer made up of boulders drowned within a brown matrix of a sandy-silty texture. Below, there is a water table which hides the rest of profile.

- **Middle unit**

This is the one exploited by the local population for earth blocks manufacturing (EM-1). It is about 110 cm in height and it is mainly clayey and reddish in colour with some particle sizes ranging from sand to gravel.

- **Upper unit**

This is the organo-mineral part of the soil profile, with a thickness of about 12 cm and displays a dark red colour with some millimetric alumino-ferrous gravels.

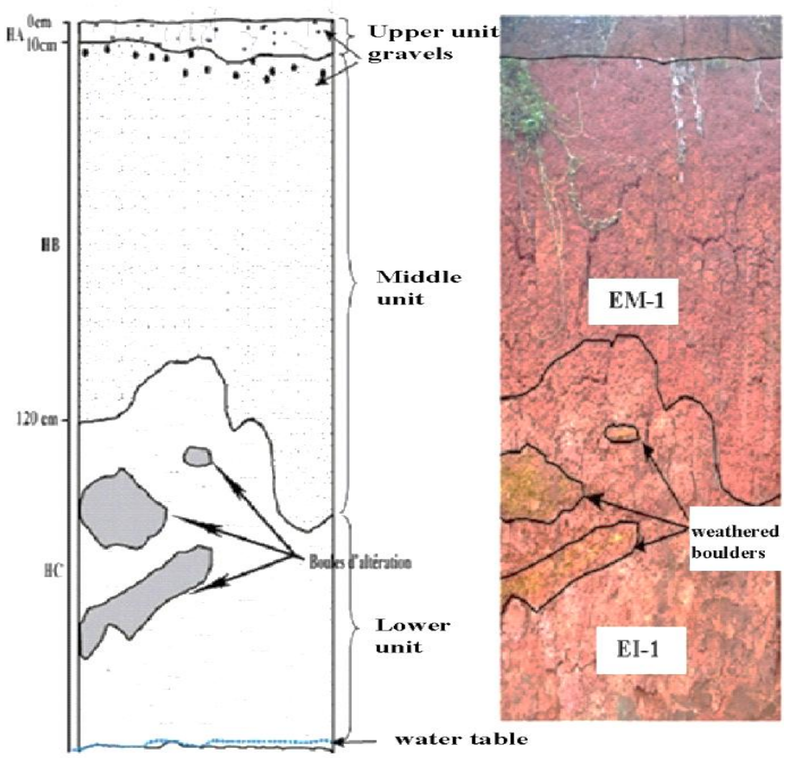

FIGURE 3: DOWNHILL SOIL PROFILE OF THE STUDY AREA

4.1.2 Top hill Profile P2 (profile of Meka'a)

This profile has been described from a trench shown in figure 4 situated at 10°02′16'″ of Easting and 05°26′30″ Northing, It is made up of three main units that is: the lower unit, the middle unit and the upper limit.

- **Lower unit**

It is constituted of two sub-units.

1. Isalterite of ignimbrite (weathering area HC_1). From a yellowish coloration, this sub-unit contains some regoliths. It is rich in quartz and feldspars and is sandy silty in texture.
2. Alloterite of weathered ignimbrite. This sub-unit is pinkish in colour and is mainly made up of clay and sand particles. It is about 180 cm of height, It is made up of a reddish matri (10R 6/2) within which are several individualized weathered boulders of diverse colourations as well as a horizon of sandy clay texture.

- **Middle unit**

This consists of two horizons, which are an upper horizon and a lower horizon. The lower horizon is a massive reddish material (illuvial/accumulation horizon HB_1). It is humid and of sticky consistency about 200 cm thick and made up predominantly of quartz. The upper horizon is heterogenous (eluvial HB_2) with a thickness of about 50 cm and is mainly made of gravely red material.

- **Upper unit represented by the organo-mineral horizon (HA)**

It is made up of an organo-mineral material of about 20 cm thick. It is brownish in colour and is predominantly made up of sand and silt particles, as well as several plant roots and some little gravels.

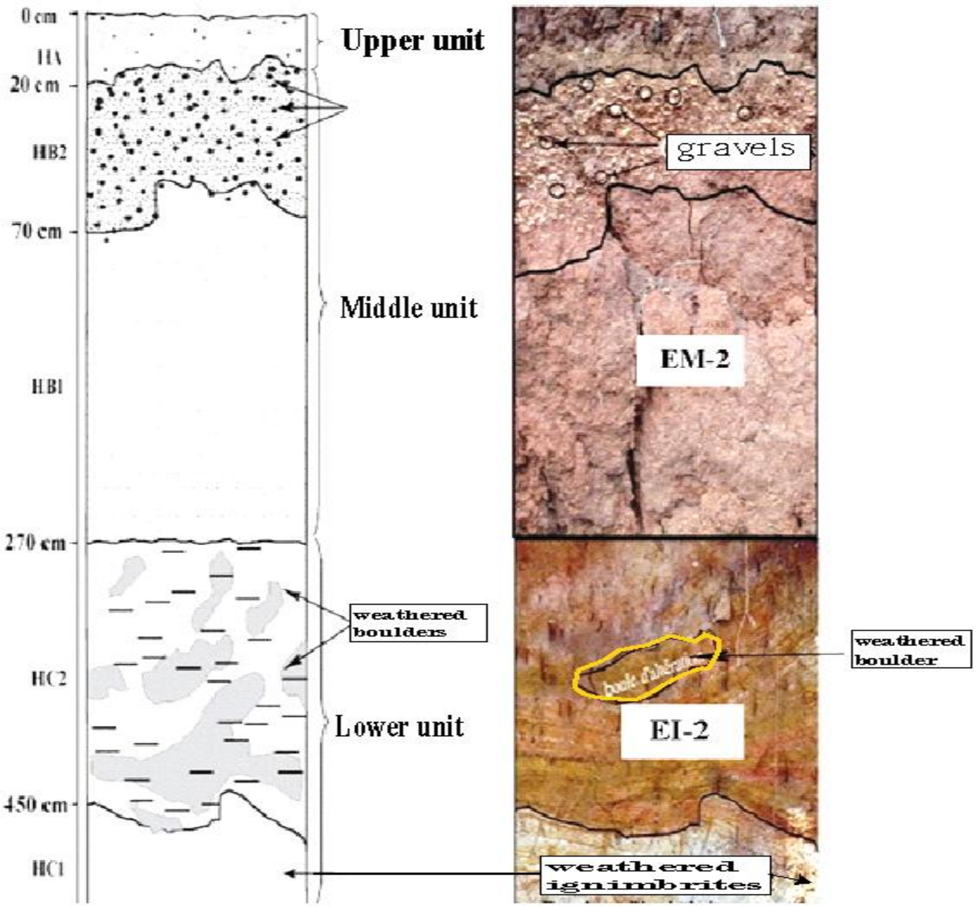

FIGURE 4: TOP HILL SOIL PROFILE OF THE STUDY AREA

4.2 Mineralogical composition of samples

The origin and the importance of the minerals present have been described by Poueme Djueyep (2012). The EM-1 and EM-2 diffractograms (fig. 5) are similar, indicating the presence of identical minerals. These minerals include residual minerals (quartz), clayey minerals (kaolinite), oxides (hematite) and hydroxides (gibbsite, goethite and lepidocrocite). The percentages of mineralogical compositions are displayed in table 1.

The mineralogical composition reveal that the weathered welded ignimbrite of Dschang yields loose soils which are rich in the kaolinite clay minerals. Upon further weathering gibbsite results indicating that the weathering prevailing in the study area is mainly of the monosiallitic type.

TABLE 1
MINERALOGICAL COMPOSITION OF SAMPLED MATERIALS (EM-1 AND EM-2)

Minerals	Kaolinite	Gibbsite	Goethite	Quartz	Lepidocrocite	Hematite
EM - 1	18%	23%	17%	31%	6%	5%
EM - 2	8%	44%	22%	12%	7%	6%

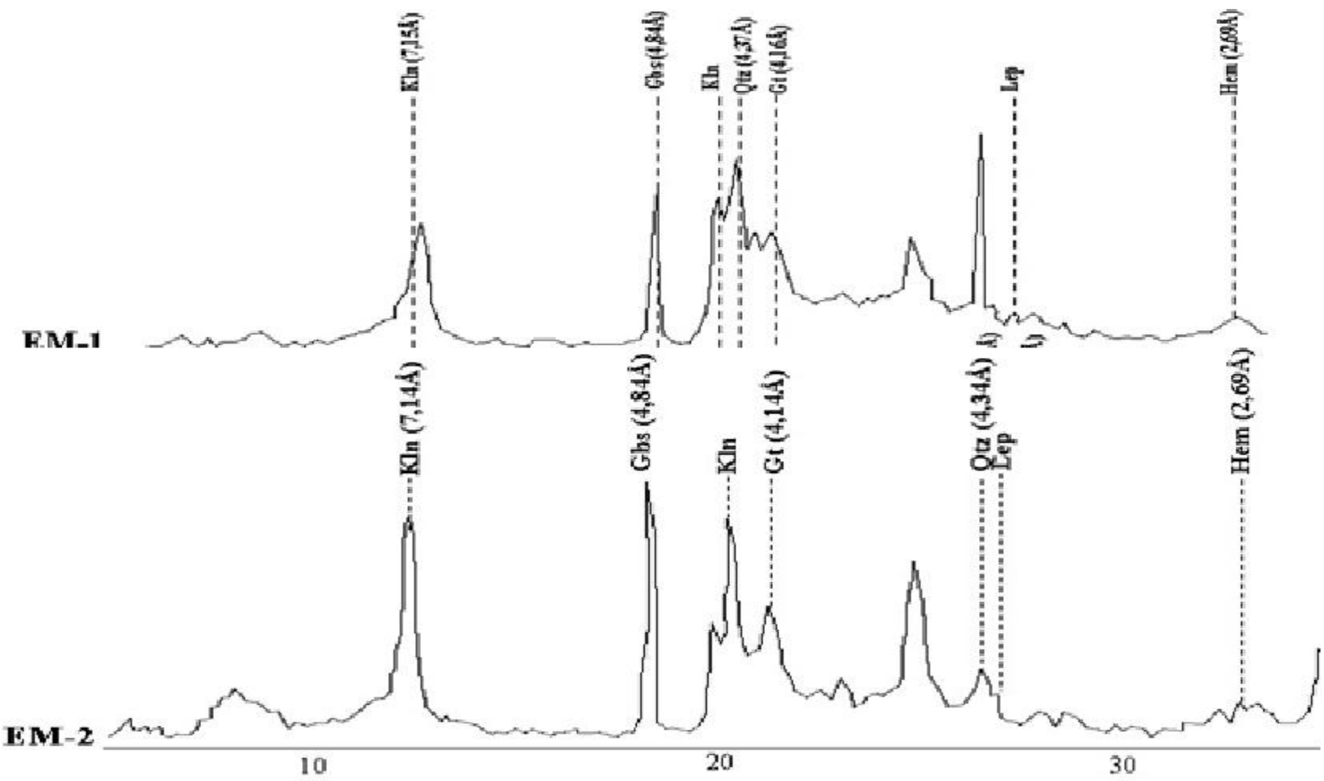

FIGURE 5: XRD CURVES OF STUDIED MATERIALS

Legend: Kln: Kaolinite; Gbs: Gibbsite; Qtz: Quartz; Gt: Goethite; Lep: Lepidocrocite; Hem: Hematite

This weathering patterns follows the « *Ignimbrite – Allophane – Kaolinite – Gibbsite* » succession presented by Atlan and Ferrer (1984) with ignimbrites of West Indian as also found by Tematio (2005) whereby he described them as typical ferrallitic soils developed on pyroclastites.

4.3 Geotechnical Parameters of studied materials

4.3.1 Physical parameters of studied materials

The physical characteristics of the sampled materials used for earth blocks production are shown in table 2 below. These represent the state of the various parameters of studied materials as determined in the field.

TABLE 2
GEOTECHNICAL CHARACTERISTICS OF STUDIED MATERIALS

Parameters	EM-1 (10-120 m)	EM-2 (70-270 m)
Apparent density : Da	1.38	1.36
Relative density : Dr	2.58	2.56
Moisture content (%) : W	61	48
Porosity (%) : n	47	47
Void index : e	0.87	0.88
Saturation degree (%) : Sr	34	26

The grain size distribution diagrams are given in figure 6 below. This is made by grain size classes as shown in the table 3.

TABLE 3
GRAIN SIZE CLASSES WITH PROPORTIONS OF STUDIED MATERIALS

Samples / Grain size classes	EM-1 (10-120 m) (%)	EM-2 (70-270 m) (%)
Gravels (Gr)	41	20
Coarse Sands (Sg)	03	08
Fine Sands (Sf)	09	07
Silts (S)	20	17
Clays (A)	27	48

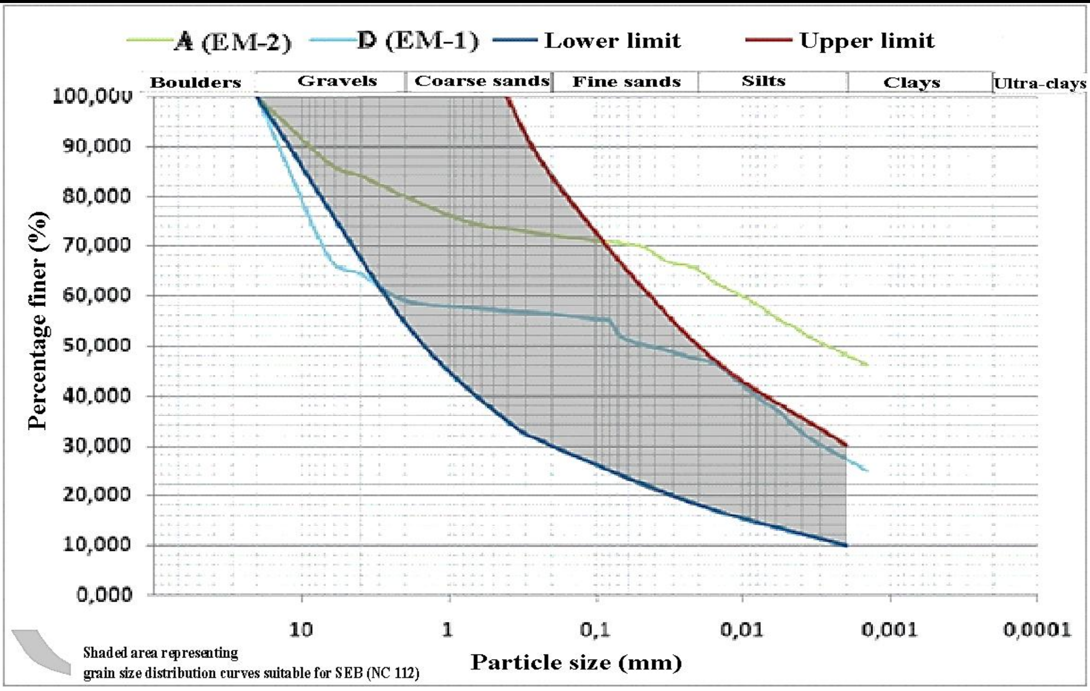

FIGURE 6: GRAIN SIZE DISTRIBUTION CURVES OF STUDIED MATERIALS

4.3.2 Consistency parameters

This entails studying the behavior of the materials with an increasing percentage of water. The results are presented in table 4 below:

TABLE 4
CONSISTENCY PARAMETERS OF STUDIED MATERIALS

Samples / Parameters	**EM-1 (10-120 m)**	**EM-2 (70-270 m)**
Liquidity limit(Wl)	102	97.4
Plasticity limit (Wp)	48.2	58.4
Plasticity index (Ip)	53.8	39
Consistency index (Ic)	0.8	1.3
Rate of clayey particles ($C_{2\%}$)	27%	48%
Main type of clay	Kaolinite	Kaolinite
Blue methylen (Ac_B)	0.5	0.1

4.4 The physical and mechanical parameters of Stabilized Earth blocks (SEB)

4.4.1 Water absorption rate

It represents the rate of water absorbed by the construction material. Samples were immersed in water for 24 hours. Values are presented in the table 5 below.

TABLE 5
WATER ABSORPTION RATE AFTER 28 DAYS OF CURING

	Water rate absorption of SEB (%)	
Cement (%)	**A (EM-2)**	**D (EM-1)**
4	wrecked	34.48
6	39.68	32.76
8	28.33	28.33

SEB made with raw materials EM-2 and with about 4% cement by weight were wrecked while those stabilized with 6 and 8% cement gave better results with 8% cement giving the lowest water absorption rate.

4.4.2 Resistance to flexural loading

With increasing of cement/soil ratio, SEB made with EM-1 horizon also display increasing flexural resistance values and about similar values for EM-2 horizon. Their values vary from 1.64 MPa to 2.44 MPa as shown in table 6.

TABLE 6
FLEXURAL RESISTANCES OF SEB

	Flexural strength (MPa)	
Cement (%)	**A (EM-2)**	**D (EM-1)**
4	1.95	1.64
6	2.07	1.98
8	2.44	2.11

4.4.3 Resistance to compressive loading

With an increase in the cement/soil ratio, the SEB showed a progressive increase in compressive resistance as shown in table 7.

TABLE 7
COMPRESSIVE RESISTANCES OF SEB

	Compressive resistance (MPa)	
Cement (%)	**A (EM-2)**	**D (EM-1)**
4	2.67	1.66
6	2.79	2.53

V. INTERPRETATION AND DISCUSSION

Results of physical parameters displayed by SEB show the necessity of some improvements. The worst characteristic is concerned with water absorption rate (which does not correspond to the prescribed value stipulated by the norm). From values of water absorption rate, resistances to compression and flexural loadings, it might be possible that the grain size distributions and the type of chemical binder are responsible of such mediocre results.

The low value of flexural resistance might be interpreted as a consequence of the bad grain size heterogeneity of those materials. Grain size analysis of the raw materials display low proportions of fine sands which does not permit the grain size curves to fall within the suitable zone for optimized SEB. This is the principal reason for lack of cohesion among particles of the material. This same effect has been recorded on the materials of Toutsang (Moimo Ndanga, 2011), which are thus not suitable for SEB.

Similarly, the water absorption rate decreases with an increase in the cement ratio. This is due to the fact that cement here, acts as a filler in between grain particles of soil. The best value of water absorption rate (28.33%) has been recorded at 8% cement. Inspite of this, it still above the recommended value by the norm which is from 10 to 15% (CRET, 88). Some of the earth blocks have been wrecked when manufactured with a mixture of 4% cement. For soil containing swelling clays, lime is more suitable as against Portland cement (CRET, 88).

According to N.C. 112 (Cameroonian norm), these blocks displayed acceptable performances with a ratio of 6% cement with regards to their mechanical properties (from 2.53 to 3.53 MPa) after 14 days of curing. Similarly, SEB made with soil materials developed on orthogneiss and granite of Toutsang are resistant to the value of 2 to 2.02 MPa (Moimo Ndanga, 2011).

VI. SOME IMPROVEMENTS METHODS

To obtain stabilized earth blocks of a better quality, it is necessary to effect some corrections with the raw materials either physically or by the use of chemical correction.

6.1 Physical correction

Due to the fact that grain size curves do not entirely fall within the ideal zone suitable for earth blocks, it might be possible to solve this problem by bringing out some improvements within grain size distributions. Standards values recognized are presented in the table 8 below:

TABLE 8
GRAIN SIZE CLASSES SUITABLE FOR SEB

Grain size classes	Proportions
Gravels	0 – 44%
Coarse sands	16 – 26%
Fine sands	12 – 34%
Silts	8 – 20%
Clays	10 – 30%

With regards to the rate of water absorption, the SEB (D) made from EM-1 material gave the better results. Physical correction can be brought about by grain size correction. This is effected by a moderate addition of sand (15% for coarse sand and 15% of fine sand). A reduction of about 35% gravels is required. Similarly for the SEB (A) obtained from material EM-2 having a high content of clays and a low content of sands, corrections were effected by the addition of 10% coarse sand and 10% find sand. With this correction, the clay content is approximately reduced by 30%.

6.2. Chemical correction

Since the SEB prepared with low cement contents (4% and 6%) do not meet the required norm, it is evident that the raw material or the quality and quantity of chemical stabilizer may not be appropriate. For economic reasons, it would be judicious to optimize SEB using the lowest quantity of chemical stabilizer but which meet the norms.

The low resistances of these SEB can be corrected by the use of hydrated lime $Ca(OH)_2$ of about 2 to 6% lime/soil ratio. This type of stabilizer is more appropriate for SEB manufacture with raw materials containing high percentages of clays (Olivier, 1994 in Abalo P'Kla, 2002). The reaction of the lime and soil is called pozzolanic reaction (Millogo, 2008), and the reactions products are calcium aluminate hydrated CAH and calcium silicate hydrate (CSH). The pozzolanic products improve upon the mechanical properties of stabilized soil. The products of pozzolanic reaction are time dependent as such the longer the curing period, the greater the strength development is enhanced. The SEB made using quick lime require a curing period of 3 to 6 months before they attain their maximal resistances.

VII. CONCLUSION

The local construction materials obtained from weathered materials developed on welded ignimbrites of Dschang display convenient preliminary characteristics which permit them to be used for Stabilized Earth Blocks (SEB) manufacture. However, they still present some few shortcomings in terms of water absorption. The compressive resistances, flexural resistances and water absorption ratio can be improved upon by physical and chemical corrections as well as improved techniques used to manufacture blocks.

ACKNOWLEDGEMENTS

All thanks to Pr. Uphie CHINJE MELO, the Director of Local Materials Promotion Authority of Yaoundé-Cameroon (MIPROMALO) and the staff of this structure who allowed their facilities for laboratory analysis of which the results have been presented herein.

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