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Determination of Mechanical Characteristics of Compressed and Stabilized Earth Blocks by Cement, by the Mixture Cement and Sawdust, and by the Lime through the Elasticity-Damaging Coupling Model

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ABSTRACT

In this contribution, we evaluate mechanical characteristics of compressed and stabilized earth blocks. We have taken two samples of earth at Yaounde in Cameroon. After the identification of their properties, we have done compression's experiments which allow us to determine the mechanical characteristics of those earth blocks. Afterwards, we have calculated the Young's modulus, the resistance in compression and the deformation limit with the measured results. The numerical methods of approximation based on the elasticity-damaging coupling model allow also to evaluate the same mechanical characteristics and the comparison between the both methods are discussed. The evaluation of other characteristics like the damaging coefficient and the damage which are difficult to measure are also exposed.

Keywords: *Compressed earth blocks, Stabilizing agents: Cement, Sawdust, Lime, Young's modulus, Deformation, Damaging coefficient, Damage.*

1. INTRODUCTION

Stabilization of earth is the set of processes which permit to ameliorate its mechanical characteristics [1]. In other to solve a stabilization problem, it's necessary to know the properties of the earth to treat and the ameliorations wish for. Stabilization permit to reduce the volume of the gap between particles of the solids, to plug up the gap which one cannot cancel and to create links or to ameliorate existing links between particles [2,3]. In our work, after manufacturing compressed earth blocks (CEB) and stabilizing it, we evaluate their mechanical properties, experimentally and numerically. The numerical method we use here, is based on the coupling elasticity damaging theory which permits to extract mechanical characteristics of materials from the experimental measurement [4]. Before any experience, we must first proceed to the identification of the properties of the earth materials.

2. IDENTIFICATION OF THE EARTH MATERIALS

We have realized experiments with two types of stabilized earth materials took in two different sites in the Yaounde region. The following earths are used:
NE**:** the earth took in Nkolbisson and,
LE: the earth took in Loudain.

2.1 Granulometry

The current granulometry gives the percentage of the three elements: gravel, sand and thin sand. Those particles are beforehand separated from the others by a first screening with a riddle with a net of 0.1m [5]. We present in the figure 1 the obtained curves after the granulometry analysis. Those granular curves are in the CRATerre zone [6]. According to this CRATerre diagram, the CEB constructions with the best qualities must be in that zone. The diagram of granulometry is made up of two axis (figure 1).

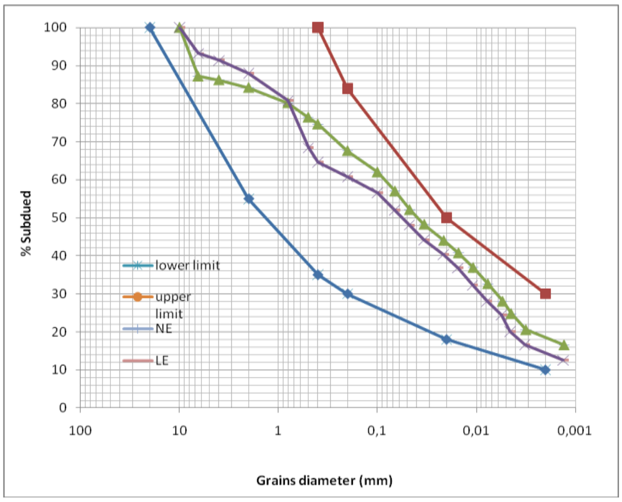

Figure 1 : Granulometric curves of NE and LE

In the x axis, we have the grain size and in the y ones, the percentage of the cumulated subdued. The granular particularities of the both earths are proposed in the following table 1.

Table 1: Granularity of the both types of Earth

Composition %	NE	LE
Mudpack	23.0	15.0
Alluvium	21.0	23.0
Fine sand	23.6	34.0
Unrefined sand	16.0	16.6
Gravel	15.8	12

2.2 Atterberg Limits

Plasticity indices Ip and the activity coefficient Ca obtained after the measurements are given in the following table 2:

Table 2: Atterberg limits of NE and LE

Sample	Ip	Ca
NE	12	0.52
LE	18	1.5

From the table 2, we can see that the earth NE is not active, while the earth LE is active according to reference [1]

3. LOCK RHEOLOGY

The trials realized on the block permit to determine the resistance to the compression Rc, the Young's modulus E, the Poisson's coefficient ν and the limit of the deformation ε_{lim} of the manufactured blocks.

3.1 Production of the CEB

The sample of the stabilized CEB has undergone 28 days cure (7 days under a plastic and 21 days under the free air). The have the parallelepiped shape of the block with the dimensions 300x140x120 mm.

3.2 Stabilizing Agents

The stabilizing agents used in the production of the test tubes are the following: the cement (CPJ 35) at 6%; the mixture cement (CPJ 35) at 4% and the sawdust at 2%, and the lime at 6%. After this step, we obtain the following compressed and stabilized blocks:

NEC: Nkolbisson compressed and stabilized earth with cement ;
NECS: Nkolbisson compressed and stabilized with the mixture cement and sawdust;
NEL: Nkolbisson compressed and stabilized earth with lime;
LEC: Loudain compressed and stabilized earth with cement ;
LECS: Loudain compressed and stabilized with the mixture cement and sawdust;
LEL: Loudain compressed and stabilized earth with lime.
The masses measurements have been done with an electronic Libra of the MIPROMALO (MIssion de PROmotion de MAtériaux LOcaux, Yaoundé-Cameroun). For each type of the earth, we have manufactured 3 test tubes for one stabilizing agent, at the end we have a total of 18 test tubes.

3.3 Density of Test Tubes

Before the tests, we have measured the mass and the density of each test tube. For each stabilizing agent and each earth type, the value of the mean density is obtained by taking the mean density of each test tubes [7]. The results are shown in tables 3 et 4:

Table 3: Density of NE Different Test Tubes

N°	Density ρ (g /cm^3)	NEC	NECS	NEL
1	ρ1	1,900	1,736	1,683
2	ρ2	2,067	1,680	1,635
3	ρ3	1,865	1,780	1,652
Mean ρ		1,944	1,732	1,656

Tableau 4: Density of LE different test tubes.

N°	Density ρ (g /cm^3)	LEC	LECS	LEL
1	ρ1	1,814	1,720	1,660
2	ρ2	1,814	1,687	1,644
3	ρ3	1,800	1,717	1,623
Mean ρ		1,809	1,708	1,642

According to our results, for the same percentage, and the same type of stabilizing agent, the density mass of NE is lightly greater than the LE one. In to the bargain for the same earth and for the same percentage, the density is greater if the cement is used as the stabilized agent, and more lower if the lime is used. The density mass obtained if the mixture of cement and sawdust is used lightly greater than lime one.

4. TESTS OF THE RESISTANCE THE MECHANICAL COMPRESSION

Those trial have been realized in the construction materials laboratory of LABOGENIE (LABOratoire national du matériel de GENIE civil) at Yaoundé in Cameroon.

4.1 Experimental Setup

The set up is constituted of one hydraulic power press [1]. After planning the test tube is laid between the trays of the test compression machine. The trials are realized by a uniformly distributed imposed load until the breaking up has happened.

4.2 Experimental Results

For each stabilizing agent and for each earth type, the value of the mean resistance to compression (Rc), is obtained by calculating the mean of each test tubes. Results are shown in tables 5 and 6.

Table 5: Experimental Values of the Resistance to Compression of NE

N°	Resistance Rc (MPa)	NEC	NECS	NEL
1	Rc1	3.35	1.15	0.70
2	Rc2	2.25	1.10	0.60
3	Rc3	2.27	1.20	0.74
Mean Rc		2.29	1.15	0.68

Table 6: Experimental values of the resistance to compression of LE

N°	Resistance Rc (MPa)	LEC	LECS	LEL
1	Rc1	2.40	1.30	0.90
2	Rc2	2.30	1.20	0.95
3	Rc3	2.56	1.25	0.94
Mean Rc		2.42	1.25	0.93

4.3 Deformation Limit of the Test Tubes

The deformation limit corresponds to the maximal stress [5]. The obtained results are shown in tables 7 and 8.

Table 7: Experimental Values of the Deformation Limit of NE Test Tubes

N°	Deformation limit ε_{lim} (%)	NEC	NECS	NEL
1	$\varepsilon_{\text{lim1}}$	1.10	1.38	1.83
2	$\varepsilon_{\text{lim 2}}$	0.97	1.52	1.60
3	$\varepsilon_{\text{lim3}}$	1.08	1.48	1.58
Mean ε_{lim}		1.05	1.46	1.67

Table 8: Experimental Values of the Deformation Limit of LE Test Tubes

N°	Deformation limit ε_{lim} (%)	LEC	LECS	LEL
1	$\varepsilon_{\text{lim1}}$	1.03	1.41	1.62
2	$\varepsilon_{\text{lim 2}}$	0.97	1.20	1.40
3	$\varepsilon_{\text{lim3}}$	0.97	1.32	1.39
Mean ε_{lim}		0.99	1.31	1.47

4.5 Calculus of the Elasticity Modulus

The elasticity modulus is evaluated from the slopes of the normal strain-stress at the 30% of the ultimate load [7] by the following formula:

$$E = \frac{\text{normal stress at 30\% of the ultimate load}}{\text{correspondent strain}} \qquad (4)$$

$$E = \frac{\sigma}{s} \qquad (5)$$

$$\sigma = E\,\varepsilon \qquad (6)$$

Where

σ (MPa) is the normal stress ;
ε (without dimension) is the strain;
E(MPa) is the Young’s modulus.

For each stabilizing agent and for each earth type, the value of the Young’s modulus is obtained by calculating the mean of the Young’s modulus of the test tubes. The obtained results for each type of earth for the trials are shown in tables 9 and 10.

Table 9: Experimental Values of the Young’s Modulus of NE of Test Tubes

N°	Young’s modulus E (MPa)	NEC	NECS	NEL
1	E1	290	116	94
2	E2	295	120	89
3	E3	300	112	93
Mean E		295	116	92

Table 10: Experimental Values of the Young’s Modulus of LE of Test Tubes

N°	Young’s modulus E (MPa)	LEC	LECS	LEL
1	E1	310	125	102
2	E2	315	127	94
3	E3	305	132	101
Mean E		310	128	99

During the test, the strain independently of the earth doesn’t show the plastic deformation. And as the consequence, during the loading, the damaging was progressing with the strain material before the stress limit. The observed deterioration was pursuing after this limit. The analysis of the strain-stress curves allows us to classify the material like one having the elasticity-damage coupling according to reference [4].

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5. NON LINEAR BEHAVIOR MODEL

This model is quietly presented in the references [4]. Here we have used it to obtain the following results.

5.1 Mechanical Characteristics

In order to evaluate those mechanical characteristics, we have first to validate the proposed modeling of the one axis behavior of the compressed earth block by the authors of the paper [4]. After this step, we go to the determination of the Young's modulus E, the strain limit ε_{lim} and the resistance to the compression Rc will help to estimate the validity of the modeling by comparison the numerical and the experimental results. The obtained results are shown in tables 11 and 12:

Table 11: Experimental Values of the Strain Limit of NE Test Tubes

N°	Strain limit ε_{lim} (%)	NEC	NECS	NEL
1	ε_{lim1}	1.10	1.38	1.83
2	ε_{lim2}	0.97	1.52	1.60
3	ε_{lim3}	1.08	1.48	1.58
Mean ε_{lim}		1.05	1.46	1.67

Table 12: Experimental Values of the Strain Limit of NE Test Tubes

N°	Strain limit ε_{lim} (%)	LEC	LECS	LEL
1	ε_{lim1}	1.03	1.41	1.62
2	ε_{lim2}	0.97	1.20	1.40
3	ε_{lim3}	0.97	1.32	1.39
ε_{lim} mean		0.99	1.31	1.47

5.2.2 Damage Coefficient

The curves of the approximations of the experimental behavior with one axis compression of each earth are shown from figure 4 to 9.

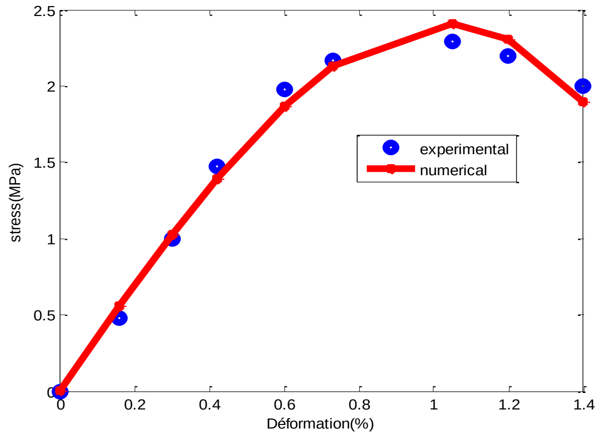

Figure 4: Comparison of numerical and experimental strain-stress curves of the NEC

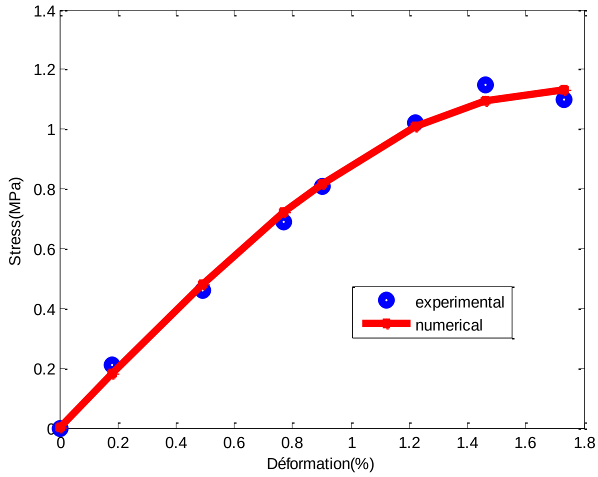

Figure 5: Comparison of numerical and experimental strain-stress curves of the NECS

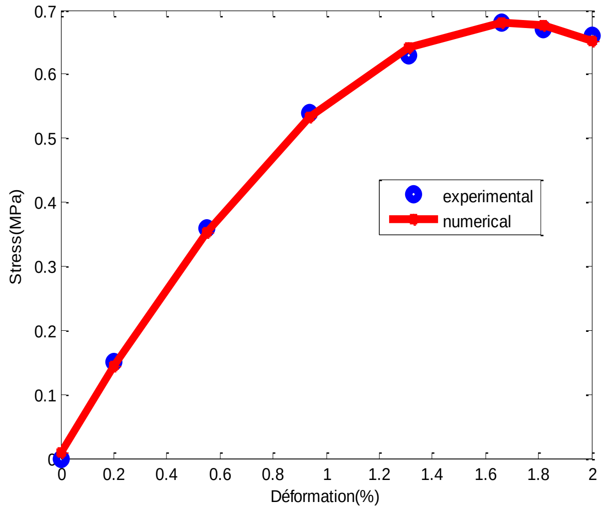

Figure 6: Comparison of numerical and experimental strain-stress curves of the NEL

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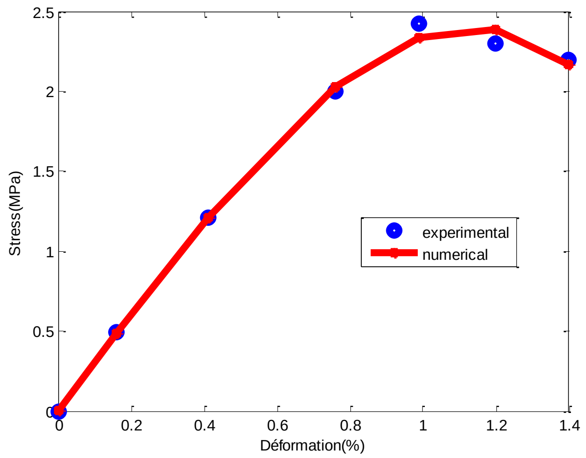

Figure 7: Comparison of numerical and experimental strain-stress curves of the LEC

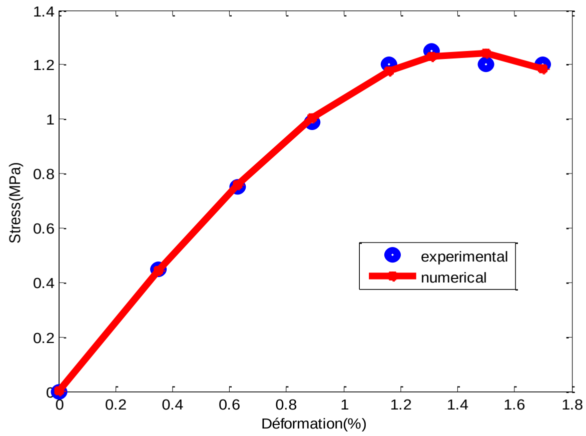

Figure 8: Comparison of numerical and experimental strain-stress curves of the LECS

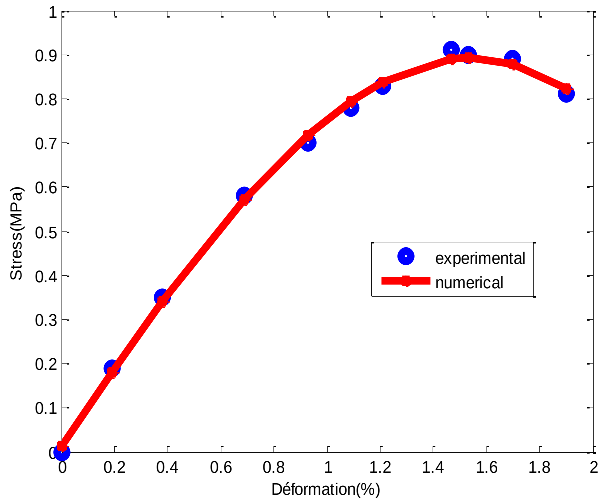

Figure 9: Comparison of numerical and experimental strain-stress curves of the LEL

In the following tables 13 and 14 which concern figures from number 4 to 9, the relative error between numerical and experimental values is lower than 10% for the strain and for the resistance. It is approximately 26% for the Young's modulus.

Table 13: Numerical and Experimental Results of NE

	E (MPa)		Rc (MPa)		ε_{lim} (%)	
	Exp	**Num**	**Exp**	**Num**	**Exp**	Num
NEC	295	349 (+18%)	2.29	2.4 (+18%)	1.05	1.03 (-2%)
NECS	116	102 (-12%)	1.15	0.96 (+18%)	1.46	1.15 (- 21%)
NEL	92	68 (-26%)	0.68	0.68 (0%)	1.67	1.67 (0%)

Table 14: Numerical and experimental results of LE

	E(MPa)		Rc (MPa)		E_{lim} (%)	
	Exp	**Num**	**Exp**	**Num**	**Exp**	Num
LEC	310	302 (-2%)	2.42	2.28 (-6%)	0.99	0.93 (-6%)
LECS	128	128 (0%)	1.25	1.25 (0%)	1.31	1.44 (+10%)
LEL	99	88 (-12%)	0.93	0.89 (- 4%)	1.47	1.55 (+5%)

5.2.3 Analysis of the Damage

The numerical determination of the damage coefficient s and the strain at the break up ε_R allow to quantify the damaging through the evaluation of the parameter D:

$$D = \left(\frac{\varepsilon}{\varepsilon_R}\right)^s \qquad (7)$$

where ε is the deformation of the material.

The figures 10 and 11 show the evolution of the damaging with the stress for the both stabilized earths. This evolution is given for the both earths until the stress limit Rc.

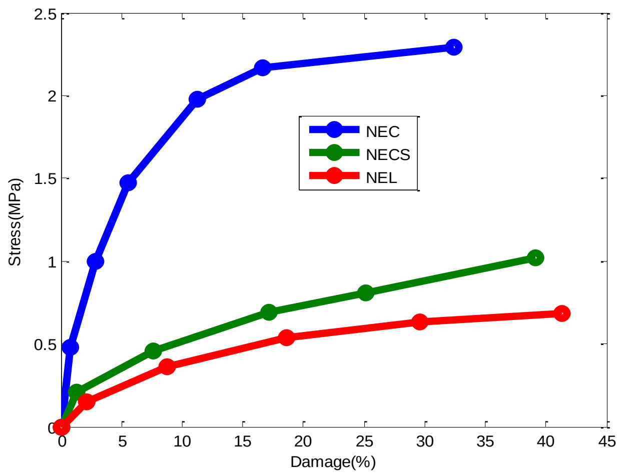

Figure 10: Evolution of the damaging in function of the loading stress for: NEC, NECS and NEL

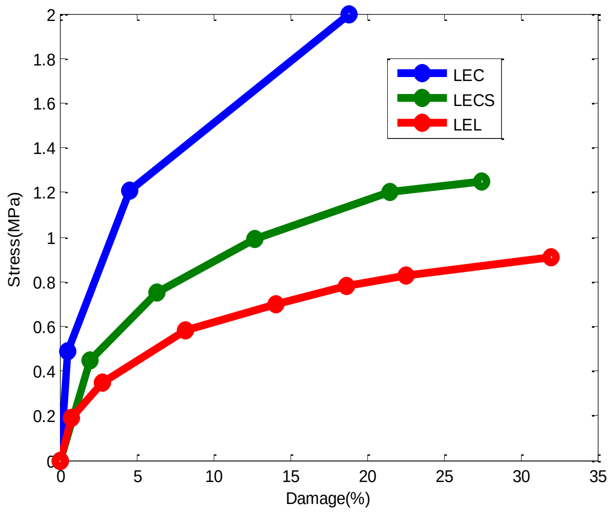

Figure 11: Evolution of the damaging in function of the loading stress for: LEC, LECS and LEL

On the figures 10 and 11, we can remark that, the damage is present and that either the material is clayey (NE or LE) more the damage is important. This behavior is due to gravels which play the role of reinforcements and confer more rigidity and less damaging to the materials. For NE, at the stress limit, the damaging has deteriorated the earth blocks at more than 30% for NEC, more than 35% for NECS and more than 40% for NEL.

For LE, at the stress limit the damaging has deteriorated the earth blocks at more than 15% for LEC, more than 25% for LECS and more than 30% for LEL. From those results, we notice that although the damage is more important in NE than in LE and according to table 1, the NE is more clayey than LE.

5.2.4 Damaging Coefficient

The values of the damaging coefficient s, is obtained by combining numerical and experimental data [9]. The values we obtain are shown in tables 15 and 16.

Table 15: Damaging Coefficient of NE

Damaging coefficient	NEC	NECS	NEL
s	2	1.8	1.4

Table 16: Damaging coefficient of LE

Damaging coefficient	LEC	LECS	LEL
s	2.3	2	1.8

According to tables 15 and 16 which emerge from the characteristics of figures 10 and 11, the damage changes with the nature of the stabilizing agent and the composition of the material. For the same earth, we obtain a damaging coefficient more raised when the cement is used and less raised when the lime is used. For the same stabilizing agent, the damaging coefficient is more raised when we used the earth L which contains a weak percentage of clay.

6. CONCLUSION

We have analyzed the Young's modulus values, the resistances to compression and the deformation limit of stabilized CEB obtained by numerical and experimental methods. The gap between the both methods for the Young's modulus is less than 30% and for the resistance to compression the gap is not greater that 10% and for deformation limits also. Thanks to the numerical methods, we have evaluated the damaging coefficient for each earth and for each stabilizing agent. The results obtained show that for any earth, the damaging coefficient is more raised for the stabilized CEB with the cement. However in order to reduce the cement consumption and when the financial means are not available, it is also possible to use the mixture cement and sawdust which has the properties closed to the cement one.

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