British Journal of Applied Science & Technology
4(21): 3003-3011, 2014

SCIENCEDOMAIN *international*
www.sciencedomain.org

Sustainable Study of Local Lateritic Soils Compressibility

Robert Medjo Eko[1], Lezin Seba Minsili[2*]
and Etone Maka Alexandre Dodo[1]

[1]Department of Earth Sciences, Faculty of Sciences, The University of Yaoundé I, Yaoundé, Cameroon.
[2]LMM Laboratory, ENSP, The University of Yaoundé I, P.O. Box 8390 Yaoundé, Cameroon.

Authors' contributions

This work was carried out in collaboration between all authors without conflicting issues. Author RME designed the study. Authors RME and LSM wrote the protocol. All Authors managed the experimental setup of the study, soils sampling, and results interpretations. Authors LSM and EMAD wrote the first draft of the manuscript and managed literature searches. The final manuscript was read and approved by all authors.

Original Research Article

Received 22nd March 2014
Accepted 2nd May 2014
Published 24th May 2014

ABSTRACT

An investigation on the compressibility and settlement duration of a lateritic soil of Yaoundé, Cameroon, was performed to check on its ease to carry loads of civil engineering structures. The increase in settlement with water content is more accentuated with a stronger load than a weaker one. The compaction also considerably decreases the compressibility of these soils, rendering the action of water almost null on the variation of settlement except when the compaction is not made with the optimum Proctor. These significant observations compel us to consider only, for a lateritic soil or another soil, the compressibility characteristics under immersion conditions. The findings of this work agree with the principle of the odometric test described in the French Standard NF P 94 900.

Keywords: Lateritic; water content; compression index; compaction; consolidation.

**Corresponding author: E-mail: lezinsm@yahoo.com;*

1. INTRODUCTION

Lateritic soils are in abundance in the intertropical zones. They are soft soils with color varying from red to yellow, rich in alumina and iron oxides and which harden when they are exposed to free air [1-3]. These soils represent a significant source of materials for the works of engineering structures such as roads, bridges and dams [4]. Their strong thickness places them naturally as the principal support of civil engineering works. When their initial structure is changed through external effects, these soils are called compressible and the process results in their settlement. This settlement phenomenon of soils sometimes causes damages on buildings like cracking of walls, collapse of buildings, and sometimes rutting of roadways. One of the various causes of this phenomenon is the variation of the water content in soils due to the variability of the country yearly water fall and the change in velocities of water absorption of different sub-soils. Several studies on the behavior of lateritic soils only take into account the saturated state to tackle the variation in soil settlement [5-7].

This research work employs alternative experimental approaches such as compressibility and settlement of local available lateritic soils in order to solve their engineering related problems.

2. METHODOLOGY

Compaction tests carried out employed odometer compression rules in accordance with standards and regulations defined by AFNOR (Association Française de NORmalisation, *French Standard Agency*). The odometer compression test was equally carried out as one of the major tests in this study. This test, performed in the loading stage (24 hours), consisted of:

- Putting the sample in a rigid envelope;
- Exerting a vertical pressure on its upper end using a piston;
- Measuring, at the end of each loading stage after consolidation, the depression leading to the determination of various characteristics of compressibility pertaining to the analyzed soil sample [8-10].

These tests were carried out on an undisturbed samples (US) taken from a lateritic profile of Yaoundé (Fig. 1) and on compacted samples (CS) carried out in the laboratory using results of Proctor compaction tests. The analysis of these samples with the odometer was done at different water content. For US, two cases of water content were retained: the natural water content (i.e. without water addition in the odometric cell) and the saturated state. In the case of compacted samples, the samples were prepared using three values of the optimal water content (w_{opm}): 80%, 100% and 120%.

2.1 Experimental Setup

The tests were carried out on two categories of samples, by means of a battery of three loading sets with weight automatics odometers (Fig. 1.d). Each apparatus comprises a cell made up with a laterally rigid ring with smooth interior walls. The ring is equipped with a cylindrical case that can receive a test-tube of 50 mm diameter and 20 mm thickness, placed between two porous stones. The whole system is placed inside a rigid vat at the bottom of which rests a lower porous stone. The vertical load is applied to the test-tube by means of a piston, on the base of which is fixed the upper porous stone. The piston slides on the ring with a weak play and a negligible friction and the load, applied by means of a weight, which is then transmitted to the test-tube by a rigid lever which takes support on the head of the piston.

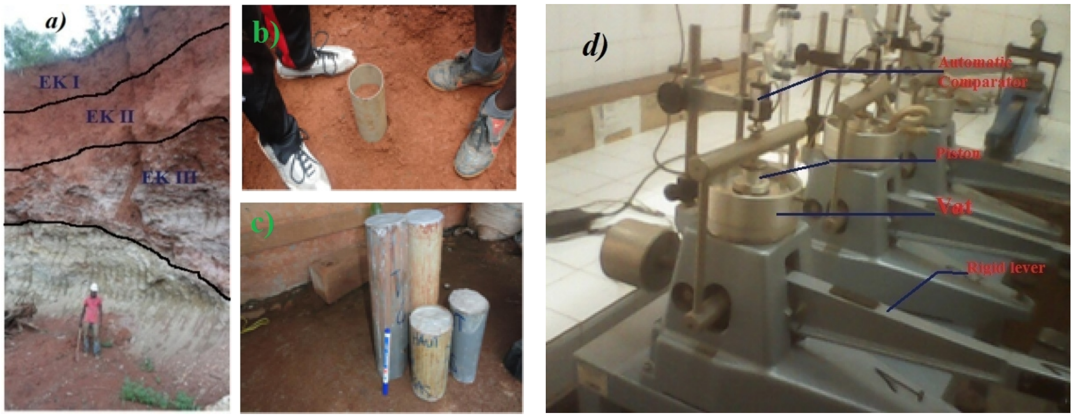


Fig. 1. Experimental setup: a) Sampling site; b) US sampling process; c) Conservation of US; d) Battery of odometers

2.2 Experimental Protocol

The execution of each test was made in accordance with the procedure recommended by Mieussens et al. [8]. However, some adjustments were made with respect to unsaturated compacted samples to accommodate the sizes of test tubes in the odometric ring.

3. RESULTS AND INTERPRETATION

3.1 Classification of Samples

The Anglo-Saxon classification HRB (Highway Research Board), based on the Atterberg limit values and the granulometry data [11], allowed us to classify the analyzed samples into A-7-5 (17), A-7-5 (6) and A-7-5 (4) classes for sample sites EK I, EK II and EK III respectively. Physical parameters obtained and the granulometric distribution of these samples are presented in Fig. 2 and Table 1.

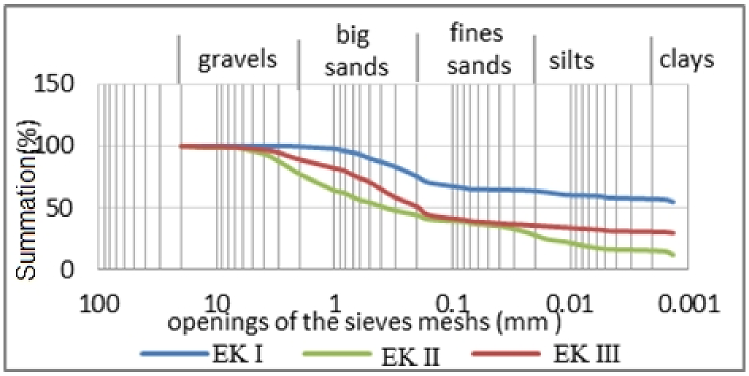


Fig. 2. Granulometric curves of analyzed samples

Table 1. Parameters identification of analyzed samples

	Physical parameters		
	EK I	**EK II**	**EK III**
W_L	73,61	67,76	62,4
I_p	40.27	34,47	18,33
d_a	1,32	1,48	1,29
d_r	2,71	2,84	2,67
w (%)	27,74	14,27	21,67
γ_h (kN/m ^{3})	16,8	16,9	15,7
γ_d (kN/m ^{3})	13,2	14,8	12,9
γ_s (kN/m ^{3})	27,1	28,4	26,7
γ_{sat} (kN/m ^{3})	18,3	19,6	18,1
e	1,06	0.92	1,07
n (%)	51	48	52
c (%)	49	52	48
w_{sat} (%)	39,02	32,27	39,95
S_r (%)	79,46	37,14	61,72

W_L= liquid limit ; I_P= plasticity index ; d_a= apparent density; d_r= real density; γ_h= wet voluminal weight; γ_d= dry voluminal weight; γ_s= voluminal weight of solid constituents; γ_{sat}= voluminal weight of saturated soil; e= void ratio; n= porosity; c= compacity; w_{sat}= saturation water content; S_r= saturation degree

3.2 Compaction

A compaction test is done to simulate the conditions under which the utilized material would be used for the construction of platforms or fills. According to BCEOM (Bureau Central d'étude pour les Equipements d'Outre-Mer, *Central Studies Office for Oversee Infrastructures*) and CEBTP (Centre Expérimental de recherche et d'étude des Bâtiments et Travaux Publiques, *Experimental Research and Study Centre for Buildings and Public Works*), values of CBR (California Bearing Ratio), presented in Table 2, place the soils of Yaounde in classes S2 (EK I and EK III) and S4 (EK II). These research offices estimated that materials of class S2 (5<CBR<10) can be used for the construction of embankments, while those of class S4 (15<CBR<30) could be well used for the construction of the foundation and roadbed for light traffics [12,13].

Table 2. Values of compaction tests

	EK I		**EK II**		**EK III**	
Proctor	γ_{dmax} **(kN/m^3)**	w_{opm}	γ_{dmax} **(kN/m^3)**	w_{opm}	γ_{dmax} **(kN/m^3)**	w_{opm}
	17,15	20.5	19,2	15,9	18,6	14,8
CBR	8%		23%		9%	

3.3 Compressibility

Tables 3 and 4 shows that, the water content increment in studied lateritic soils causes an increase of compression (Cc) and swelling index (C_g) [14,15] with a reduction in the void ratio (e) under constant load. Moreover, this variation of water content seems not to affect the consolidation stress (σ'_p) in the case of US and not CS. This variation of the consolidation stress with water content for compacted samples could be the result of compaction errors. These errors are possibly due to human factors of the experimenter while performing the Proctor test.

Table 3. Results of US compressibility

Characteristics of compressibility	EK I		EK II		EK III	
	Sat	**Usat**	**Sat**	**Usat**	**Sat**	**Usat**
Cc	0.376	0.348	0.376	0.199	0.294	0.282
Cg	0.014	0.009	0.009	0.003	0.019	0.010
σ'_p (bars)	0.55	0.55	1,00	1,00	1,40	1,40
e	0.970	1,140	0.898	0.960	0.855	1,010

3.4 Settlement Analysis

Settlement calculations are done according to the Terzaghi law.

$$s = \frac{Ho}{1+eo}\left[Cg \times \log\left(\frac{\sigma'p}{\sigma'vo}\right) + Cc \times \log\left(\frac{\sigma'vo + \Delta\sigma'}{\sigma'p}\right)\right]$$

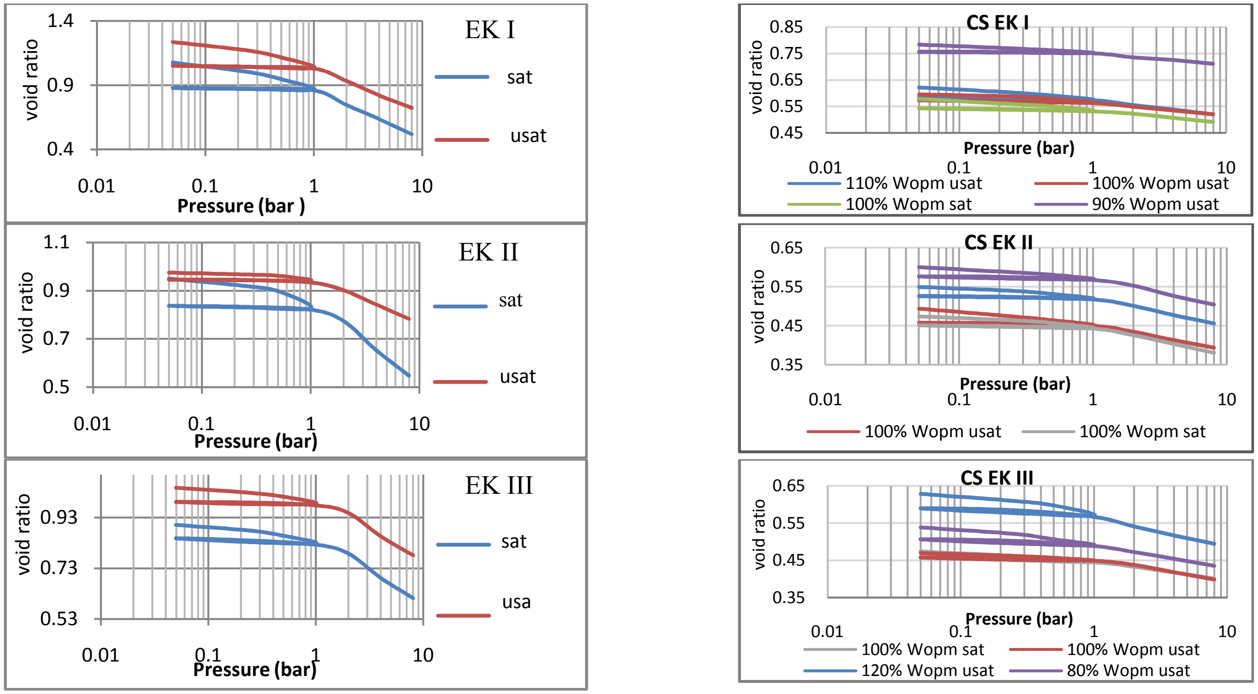
Where H_0 is the average thickness of the horizon and σ'_{v0} is the original constraint. Their values are respectively *0.168 bar* and *200 cm* for EK I, *0.76 bar* and *250 cm* for EK II, and *1.22 bar* and *400 cm* for EKIII.

The settlement variation curves, as function of the load, shows that the settlement value increases with water content and especially that, this increase is as larger as the value of the load. This implies that the settlement induced by lower pressure (stresses) on the soil is less affected by the water content variation than that of the settlement induced by high pressure on the soil. With regard to compacted samples, the curves of Fig. 4.a show that the ground with high CBR (EK II) is least affected by the variation of settlement when we change from one state of water content to another (saturated or unsaturated). The thickness of the compacted bed taken at 70 cm according to Bufalo et *al* [16], the curves of Fig. 4.a (CS EK III) show that the settlement is higher when the compaction is not made with the Proctor Optimum [17]. The time of settlement here is given by the relation: $t = \frac{Ho^2 \times Tv}{4 \times Cv}$

Fig. 4b gives the evolution of settlement in these soils as function of time (T_V= time factor; C_v= consolidation ratio). Concerning the US, we note that, the duration of settlement under weak loads (1 bar) is higher than under high loads (4 bars) when the soil is saturated. This progression of the settlement duration is related to the degree of lubrication of the grains of the soil. When the soil is saturated, friction between the grains is almost null, so under heavy loads, the grains will move faster during settlement. However, the contact area between the grains being higher, the resistance of the soil to settlement might nullify the settlement increment under low pressure. In general, whatever the load, these curves show that the settlement duration increases with the water content. For the CS, we note in general that, the time of settlement is slightly higher for the compactions with 100% w_{opm} (more precisely for the saturated cases).

Table 4. Results of CS compressibility

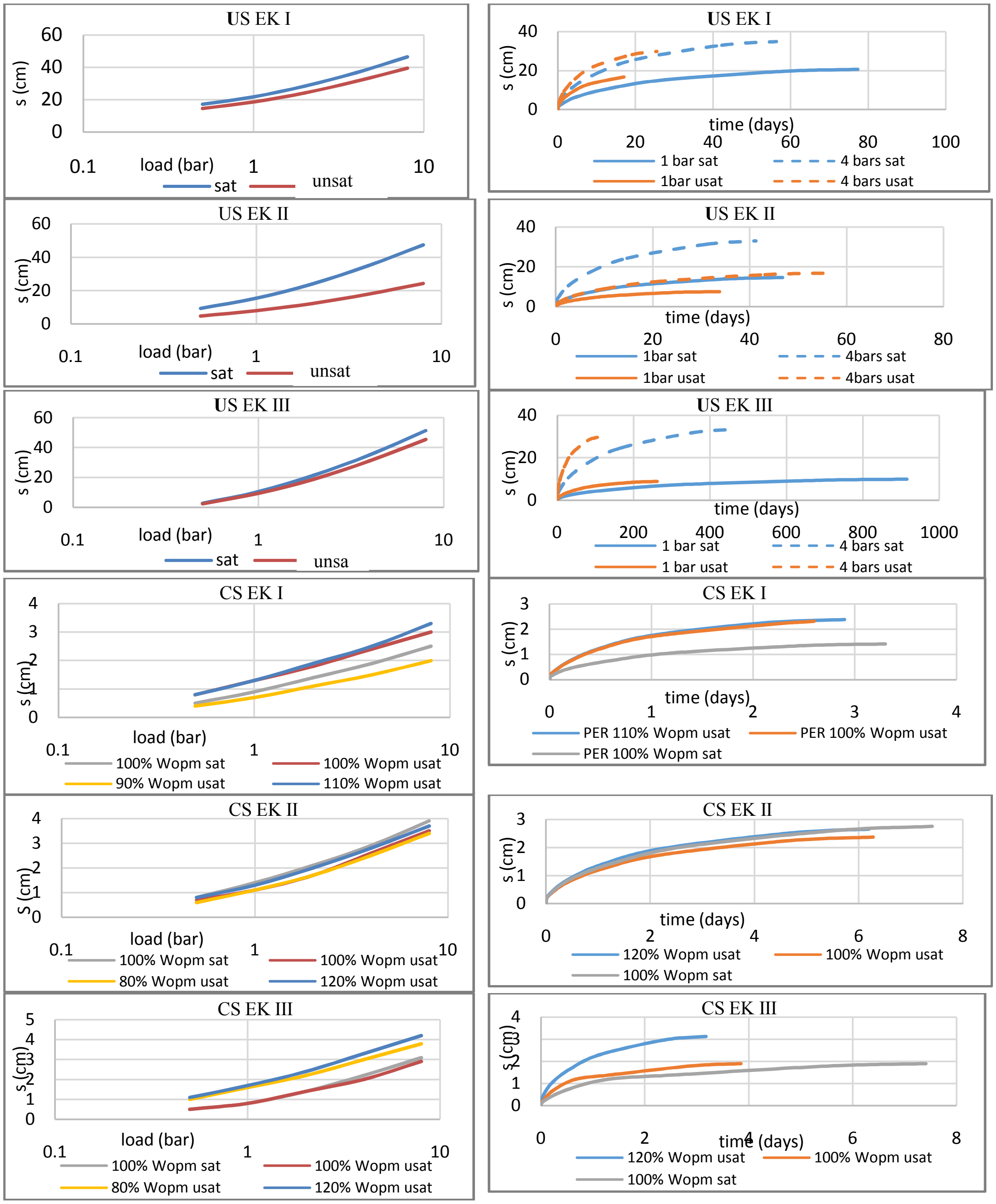
Characteristics of compressibility	**EK I**				**EK II**				**EK III**			
	90% W_{opm} (usat)	110% W_{opm} (usat)	100% W_{opm} (usat)	100% W_{opm} (sat)	90% W_{opm} (usat)	110% W_{opm} (usat)	100% W_{opm} (usat)	100% W_{opm} (sat)	90% W_{opm} (usat)	110% W_{opm} (usat)	100% W_{opm} (usat)	100% W_{opm} (sat)
Cc	0.048	0.060	0.049	0.051	0.081	0.074	0.068	0.074	0.061	0.076	0.066	0.054
Cg	0.004	0.007	0.008	0.009	0.007	0.007	0.006	0.006	0.014	0.018	0.007	0.011
σ'_p (bars)	0.74	0.50	0.35	0.70	1,00	0.70	0.85	0.70	0.37	0.45	1,20	0.90
e	0.759	0.596	0.586	0.547	0.578	0.534	0.460	0.458	0.516	0.602	0.458	0.452



a) US

b) CS

Fig. 3. Curves of compressibility for (a) US and (b) CS



a) curves of settlement as function of to load

b) variations of settlement as function of time

Fig. 4. Settlement (s) diagrams as function of load (a), and of time (b)

4. CONCLUSION

This research work assessed both undisturbed and compacted in-situ local lateritic soils as low cost engineering materials. The results obtained display important geotechnical properties which are widely influenced by environmental, loading conditions and human factors. Considered natural soil samples were saturated and unsaturated, disturbed and undisturbed, and they displayed the following behaviors affecting compaction and settlement:

- the compression and swelling indexes increase with the increment of the water content, and with the reduction in the void ratio under constant load;
- the settlement value increases with water content;
- the settlement induced by lower pressure on the soil is less affected by the water content variation than the one induced by high pressure;
- the duration of settlement under weak loads is higher than the one under high loads when the soil is saturated and undisturbed;
- CS with high CBR are least affected by the variation of settlement when we change from one state of water content to another.

It appears very important and straight forward, for a lateritic soil foundation below an infrastructure, to decrease the pressure exerted on these soils by redesigning dimensions of load application surface, or applied loads intensity and settlement amplitudes, when the soil is saturated in order to comply with existing safety requirements. For the design and construction of traffic loads above platforms, the materials with strong CBR would be adapted due to the fact that, their settlement varies very little depending on whether they are compacted with the optimum Proctor or not.

COMPETING INTERESTS

Authors declare that there are no competing interests.

REFERENCES

1. Aubert G. Les sols latéritiques. Extract from the proceedings and render accounts of the fifth International Congress of Soil Science, Léopoldville, 16 – 21 août. 1954;I:103–118.
2. Maignien R. Report research on lateritic soils. 1964;243.
3. Bilong P. Characteristics of lateritic soils with plinthite and pétroplinthite developed on acid rocks in the forest region of south Cameroon. Compared with soils developed on basic rocks. Cah. Orstom, sér. Pédol. nº2. 1992;27:203–224.
4. Sikali F, et al. Mir Jalal-Emarati. Use of laterite in road building in Cameroon. Article de revue du labogénie, nº16 février. 1988;288.
5. Bougeon G, Gunnell Y, et al. Laterite of Buchanan. Extract of the study and soil management. 2005;12(2):87–100.
6. Nguetnkam JP, Kamga R, Villieras F, Ekodeck G E, et al. Yvon J. Alteration of the granite in the tropics. Example of two sequences studied in Cameroon. Extract of the study and soil management. 2007;14(1):31–41.
7. Anuchit Uchaipichat. An Elasto-Plastic Model for Unsaturated Soils Including Effect of Drying and Wetting on Loading Collapse Curve. Electronic Journal of Geotechnical Engineering. 2011;16:476-498.

8. Mieussens C, Magnan JP, Soyez B, et al. Compression test oedometer recommended by laboratory procedures bridges and roads, bulletin liaison labo P. et Ch. 1985;139:3034.
9. Khemissa M. et Magnan JP. Variability of the results of oedometer tests on soft clay Guiche. Bulletin des laboratoires des ponts et chaussée – 227 – juillet – août. 2000;4326:41–50.
10. Gao Lei, Zhou Qiu-yue, Yu Xiang-juan, Chen Zhi-hui. Analysis and model prediction of subgrade settlement for Linhai highway in China. Electronic Journal of Geotechnical Engineering. 2014;19:11-2.
11. Callaud M. Cours de mécanique des sols – tome 1. 2iE. 2004;137.
12. Anonyme. Manual on the roads in tropical and desert areas. Ministry of Cooperation, BECEOM-CEBTP-France. 1975;48.
13. Ghassemi, Ali Pak, Hadi Shahir. Numerical study of the coupled hydro-mechanical effects in dynamic compaction of saturated granular soils. Computers and Geotechnics. 2010;37:10–24.
14. Bakarri A. Observation and modeling of earthwork subjected to drying process and humidification. Thèse ENPC. 2007;253.
15. Fidelis O. OKAFOR and Ugochukwu. N. OKONKWO. Effects of Rice Husk Ash on Some Geotechnical Properties of Lateritic Soil. Leonardo Electronic Journal of Practices and Technologies. 2009;15:67-74.
16. Bufalo M, Gandile D, Vezole P. Guide for earthworks platforms buildings and industrial areas in the case of sensitive soils to water. Syndicat Professionnel des Terrassiers de France. 2009;42.
17. Meissa Fall. Notes on lateritic materials and some results on laterites Senegal. Extrait de thèse de doctorat INPL Nancy-France; 1993.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=541&id=5&aid=4688