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Prediction of Swelling and Effects of Sand on Swelling Clays from the Far North Region of Cameroon

Baana Abouar[1], Pr Mamba Mpélé[2], Kidmo Kaoga Dieudonné[3], Moundom Amadou[4]

[1]PhD Researcher, Department of Civil Engineering, National Advanced School of Engineering, University of Maroua, Cameroon. Po Box:46 Maroua – Cameroon

[2]Professor, Department of Civil Engineering, National Advanced School of Engineering, University of Yaoundé I, Cameroon. Po Box: 8390 Yaoundé – Cameroon

[3]PhD Senior lecturer, Department of Renewable Energy, National Advanced School of Engineering, University of Maroua, Cameroon. Po Box:46 Maroua – Cameroon

[4]PhD Researcher, Department of Rural Engineering, University of Dschang, Cameroon. Po Box:2701 Douala – Cameroun

***ABSTRACT**: Swelling soils are the cause of many dilapidations of construction works around the world. In this article, samples of swelling soils (also referred to as karal), were taken from the cities of Maroua and Fotokol in the Far North Region of Cameroon, and were screened and studied. If the Casagrande and Dakshanamurthy diagrams, as well as correlations defined by some researchers confirm the swelling nature of this soil, conversely, other correlations which produced negative results had to be adjusted for them to become positive. The addition of sand during the compacting of the sand and karal blend shows that swelling reduces when the percentage of sand increases. As a matter of fact, when the percentage of sand increases from 0 to 40%, the swelling rate is 60%, 58,5% and 79% for 10, 25 and 55 strokes.*

KEY WORDS: Karal, sand, swelling.

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I. INTRODUCTION

Swelling soils greatly impact the lifespan of construction works. The swelling of these soils is often observed in dry and semi-dry areas which are characterized by a dry and hot weather, followed by a rainy period, which lead to significant fluctuations of moisture content in great depths (M. Lamara, 2006).

Cameroon's Far-North Region is largely made of this type of soil which is generally called 'karal'. This soil is made up of very thin particles (clay minerals) such as illite and montmorillonite which are essential components. Major damages are inflicted on buildings and construction works by its swelling.

Swelling entails many physical, chemical and mechanic phenomena due to the interaction of the rock with water at several intermingled stages (Jean François Serratrice, 1996). Consequently, several geotechnical parameters such as the plasticity index, initial water content, the liquidity threshold, the shrinkage index, the mass, etc. are used to predict the swelling potential using diagrams or mathematical models proposed by various researchers.

It is therefore necessary to identify these soils and predict their swelling patters before launching a construction works project so as to provide appropriateremedial measures if need be. One of the methods used to improve the geotechnical features of these soils is stabilization.

This article presents the results of a survey carried out on the prediction of swelling and the effect of sand on the swelling rate of swelling soils from the Far-North Region of Cameroon.

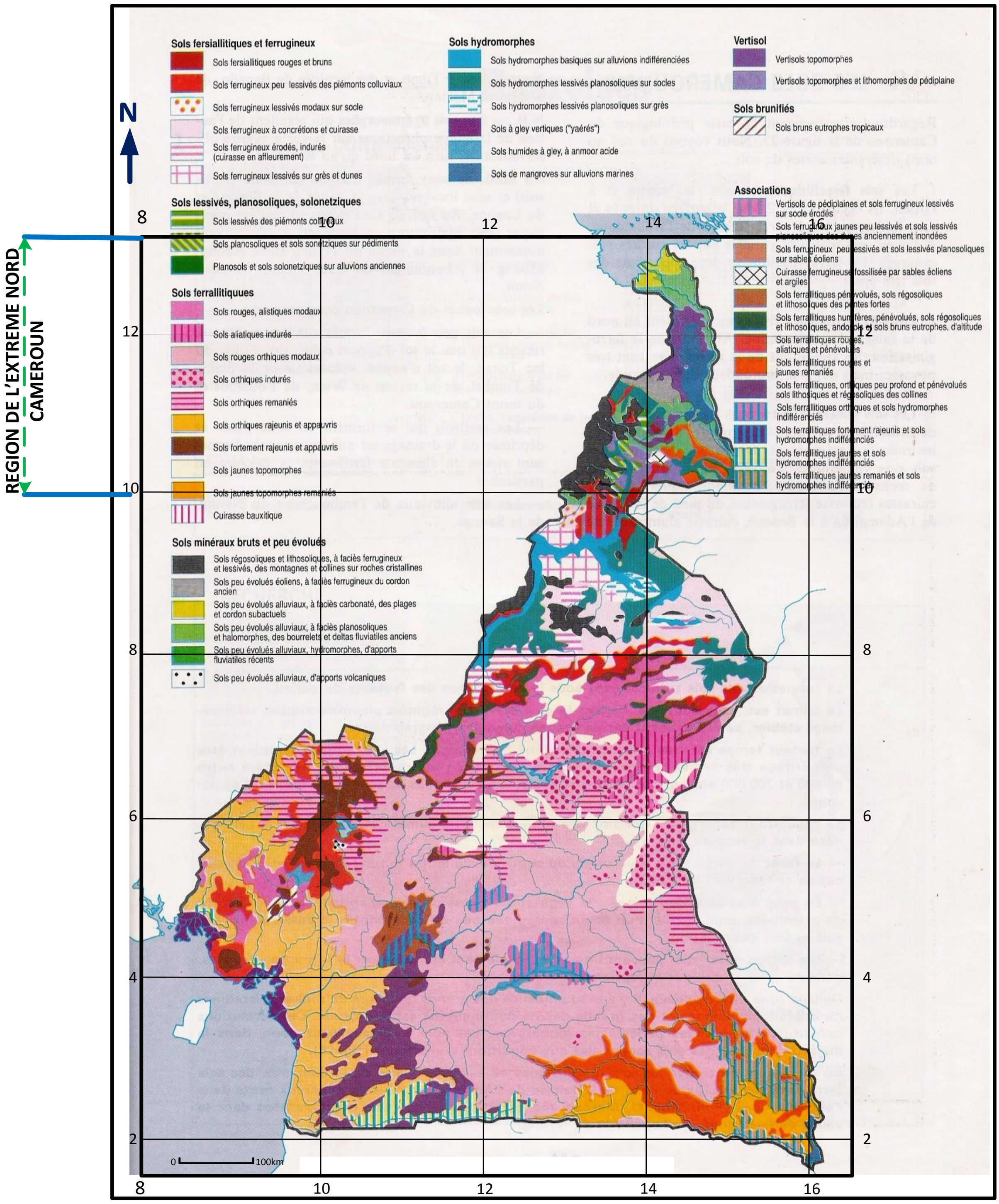

Figure 1 : Cameroon's geology and location of soils in the Far-North Region of Cameroon (Dumort J. C. 1968).

II. METHODOLOGY

2.1 Equipment

2.1.1 Origin ofsoils

Samples of soil used were taken, for the first site, from an area near the town of Maroua, precisely at Balaza, not far away from Regional Road R0905. As far as the second site is concerned, it was in Fotokol; soil samples were taken from an area near National Road No.1A.

In order to assess the effect of physical and chemical properties on volume variations of clayey soils, it is important to identify the various parameters that contribute to these effects, then consider them in the models of behaviour (Gérard Bigot et al, 2000).

Both samples underwent geotechnical tests in the Civil and Mechanical Engineering laboratory of the Yaounde National Polytechnic School. These soils' main characteristics are summarized in Table I below.

Table 1: Features of karal samples from Maroua and Fotokol

	w_n (%)	W_l (%)	W_p (%)	I_p (%)	C_2 (%)	ρ_{dopt} (t/m^3)
Maroua	27.75	56.84	31.64	25.2	45	1.9
Fotokol	30.71	53.49	27.06	26.43	35	1.93

According to Table 1, swelling clay samples from Maroua and Fotokol belong to the soil category with a strong swelling potential in the sense of Holtz et al (1973).
Features drawn from these surveys are nearly identical to those drawn from the study on the Waza-Maltam road (ISTED, 1988).
The fair grey sand used comes from the Sanaga River. It was chosen because it has the same structure and chemical content that the sand found in the northern part of Cameroon (Baana et al. 2015).

2.1.2 Equipement used

The equipment used respects the NF P 94-078 standard
The equipment to produce test tubes includes:

- The CBRmould
- The modified Proctor compacting beetle
- Accessories (raiser, space disc, levellingruler, etc.)
- Current use equipment (scales, autoclaves, containers, etc.)

The hallmarking equipment includes a press equipped with:

- A cylindrical steel chisel of 49.6mm diameter
- A device to drive the chisel into the material at the speed of 1.27mm/min
- A device to measure the speed at which the chisel penetrates the material
- A device to measure hallmarking efforts

Submersion equipment, including several containers of sufficient heights,to enable test tubes are completely submerged.

2.2. Methods

2.2.1. Tests carried out

Granulometric, sedimentometric, CBR and swelling tests were carried out on swelling clay samples mixed with sand.

a. Granulometricand sedimentometric tests

Granulometric and sedimentometric tests performed on the Maroua and Fotokol sand and swelling soil samples followed the procedure defined by the ASTM D 422-63 standard.

b. CBR and swelling tests

CBR and swelling tests were carried out following the procedure described in the NF P 94-078 standard.

2.2.2. Compounds produced

Soil samples from the various sites were mixed with 0, 10, 20, 30 and 40% of sand. Table 2 summarizes the various percentages of compounds made.

Table 2: Various compounds studied

Soil 1 compound	Soil 2 compound
0S+K1	0S+K2
0.10S+0.90K1	0.10S+0.90K2
0.20S+0.80K1	0.20S+0.80K2
0.30S+0.70K1	0.30S+0.70K2
0.40S+0.60K1	0.40S+0.60K2

Submersion is done so that the test tube is covered by about 20 mm of water above and that there is a 10 mm of water layer beneath the mould. After four days of submersion, the mould and the test tube in the container are taken out after draining; then stamping is carried out.

The measurement of swelling after 4 (four) days of saturation was done following the procedure described in the ASTM D4546-90 standard (American Society for Testing and Materials). The tendency of the mixture to swell is neutralized by applying an increasing load as soon as the compactor movement gets at 1/100mm. When the sample is stabilized, the load value represents the swelling pressure (Chen, 1988).
The methodology adopted was first to identify the soil samples used and then to measure the swelling.
In continuous environment mechanics, the swelling rate ε of a clayey material is defined as its volume variation ΔV subjected to variations of its water content divided by its initial volume V_0, (Ali El Yaakoubi, 2014).

$$\varepsilon = \frac{\Delta V}{V_0} \qquad (1)$$

Given that a swelling soil's liquid threshold and plasticity index vary in the same line with the swelling pressure (Seed H. B.), we used well graded sand which is a natural dense deposit with a high bearing capacity so as to reduce the compound's liquidity threshold or plasticity index, thereby reducing the swelling potential.

2.2.3. Diagrams and correlations used

To predict swelling, we used the swelling diagrams proposed by Dakshanamurthy et al. (1973) and Millogo (2008), as well as correlations proposed in literature, by authors includingSeed et al. (1962), Nayak and Christensen (1971), Vijayvergiya and Ghazzaly 1 (1973), Vijayvergiya and Ghazzaly 2 (1973), Schneider and Poor (1974).

III. RESULTS AND DISCUSSION

3.1 Granulometry

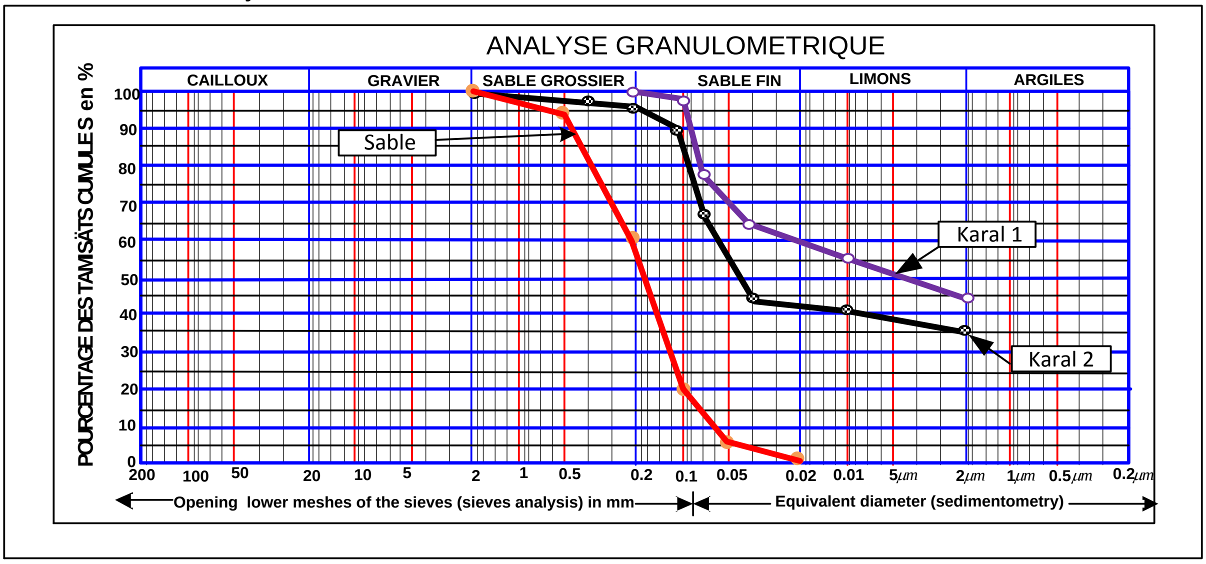

Figure 1:*Granulometric analysis results.*

Granulometric analysis results summarized in Figure 2 and Table 1 show that karals 1 and 2 contain 45% and 35% clayey materials respectively. These clayey contents are confirmed by studies carried out by Gwet H. (1992) which show that karals taken from along the Maroua-Yagoua road in the town of Moulvoudaye in the Far-North Region of Cameroon contain more than 30% of clayey materials.

3.2 Swelling Prediction

Swelling prediction is based on the Casagrande plasticity diagram (1948) and Howard plasticity diagram (1973) as well as the swelling diagrams proposed by Dakshanamurthy et al. (1973) and Millogo (2008).

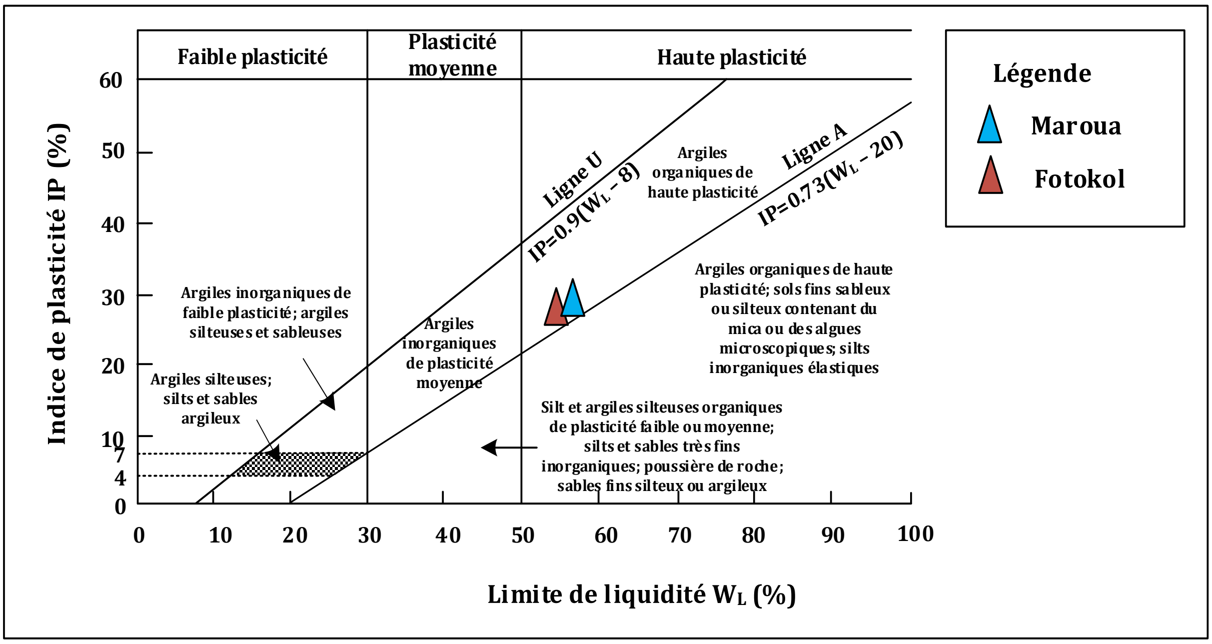

Figure 2: Plasticity diagram (according to Casagrande, 1948 and Howard, 1977)

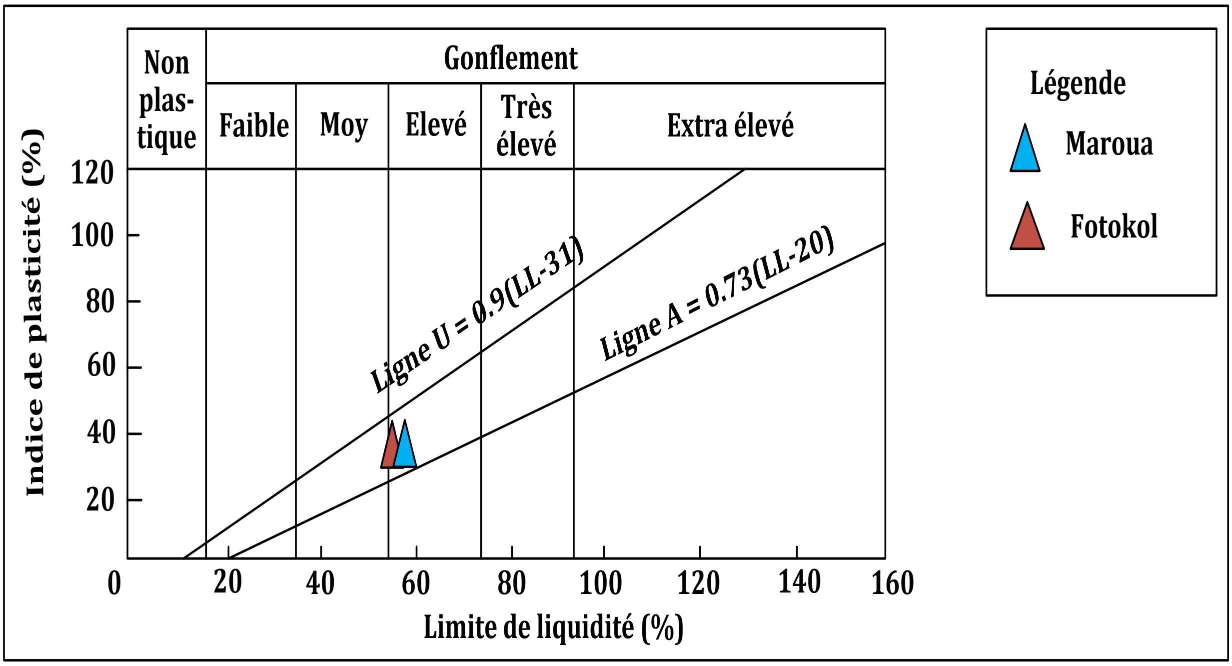

Figure 3:Swelling potential by Dakshanamurthy and Raman (1973)

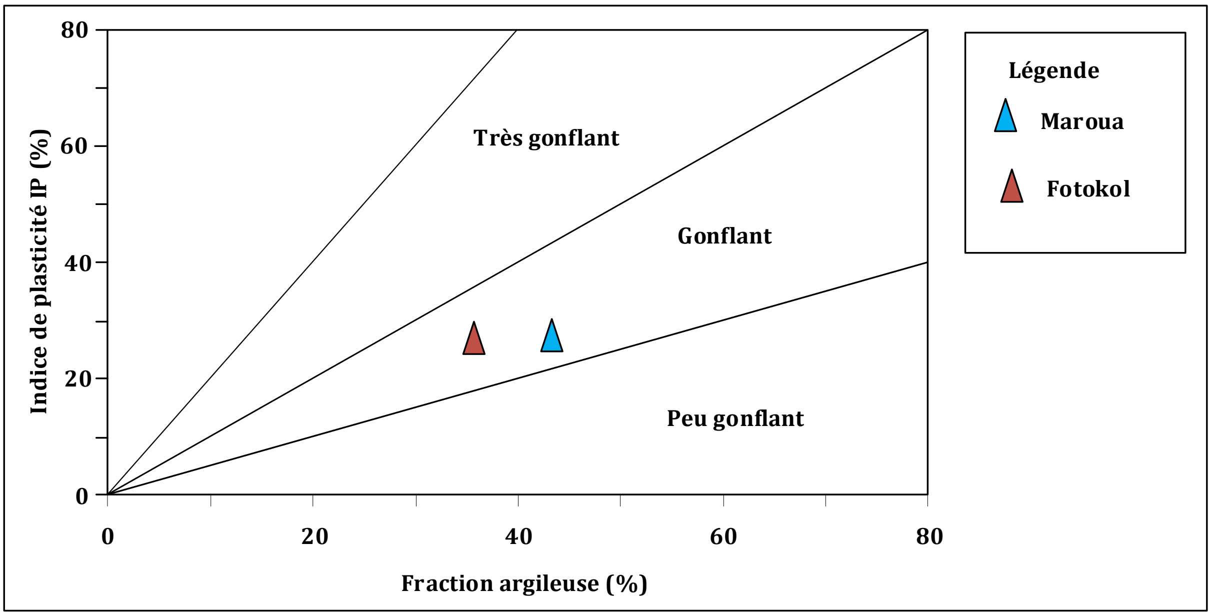

Figure 4 :Soils classification areas according to their swelling potential (Millogo, 2008)

Using swelling diagrams proposed by Dakshanamurthy et al. (1973) and Millogo (2008), it appears that tested soils are of swelling nature (Figures 3 et 4).

In order to put correlations proposed by literature to test, we used expressions in Table 3.

Table 3: Some correlations to estimate soil swelling

Model and reference	Parameters used	Adjusted mathematicalExpression
Seed et al. (1962)	I_p	$\varepsilon = 2,16 * 10^{-3} * I_p{}^{2,44}$
Nayak and Christensen (1971)	I_p, C_2, w_n	$\varepsilon = 0,0229 * I_p{}^{1,45} * \frac{C_2}{w_n} + 6,38$
Vijayvergiya and Ghazzaly 1 (1973)	W_L, w_n	$log\ \varepsilon_g = 0,033W_L - 0,083w_n + 0,458$
Vijayvergiya and Ghazzaly 2 (1973)	W_L, ρ_d	$log\ \varepsilon_g = 0,033W_L + 0,00321\rho_d - 6,692$
Schneider and Poor (1974)	I_p, w_n	$log\ \varepsilon = \frac{0,9 * I_p}{w_n} - 1,19$

Experiments on swelling (or expansive) soils show that a soil's swelling rate should increase proportionally to mass, liquidity threshold, clay content, plasticity and shrinkage indexes as well as pre-strengthening pressure (Seed et al., 1962 ; Ranganathan and Satyanarayana, 1965 ; Nayak and Christensen, 1971 ; Vijayvergiya and Ghazzaly, 1973) quoted by Zohra Derriche and Mustapha Kebaili (1998).

A look at the models shows that Seed et al. Used a single parameter: the plasticity index. Nayak and Christensen used three parameters: plasticity index, clay content and water content. Vijayvergiya and Ghazzaly 1 and 2 used two parameters: liquidity threshold and mass; and liquidity threshold and mass respectively. Schneider and Poor for their part used plasticity index and water content.
Results obtained from the granulometric analysis data and plasticity tests used to predict swelling are summarized in Table 4.

Table 4: **Provisional swelling results for the Maroua and Fotokol karalprovided by correlations proposed by literature.**

Model	Seed et al. (1962)	Nayak et al. (1971)	Vijayvergiya et al. (1973,1)	Vijayvergiya et al. (1973,2)	Schneider et al. (1974)
Maroua	5.67%	10.38%	1.03%	3.61%	0.69%
Classification	Swelling soil	Swelling soil	Non swelling	Non swelling	Non swelling
Fotokol	6.37%	9.39%	0.72%	3.55%	0.66%
Classification	Swelling soil	Swelling soil	Non swelling	Non swelling	Non swelling

Soil is considered as swelling when the swelling rate is above 5%. A close analysis of these results shows that karal from Maroua and Fotokol are swelling soils according to Seed et al. (1962), Nayak et al. (1971). On the contrary, for Vijayvergiya et al. (1973, 1,2) and Schneider et al. (1974) this karal could be non swelling soils: this contradicts results arrived at using the Dakshanamurthy et al. (1973) and Millogo (2008) diagrams.

These results show that the plasticity index and percentage of clayey particles could be more reliable parameters to assess the swelling prediction of soils used in the study. The use of the liquidity threshold as parameter seems unable to produce desired results. To correct this contradiction, we proposed revised correlations as proposed in Table 5, which give right results as shown in Table 6.

Table 5: **Modèles de prévision ajustés aux karal**

Model and reference	Parameters used	Adjusted mathematicalExpression
Seed et al. (1962)	I_p	$\varepsilon = 2*10^{-3}*I_p{}^{2,6}$
Nayak and Chritensen (1971)	I_p, C_2, w_n	$\varepsilon = 2{,}29*10^{-2}*I_p{}^{1,45}*\frac{C_2}{w_0}+6$
Vijayvergiya and Ghazzaly 1 (1973)	W_L, w_n	$\log \varepsilon_g = 0{,}055W_L - 0{,}052w_n + 0{,}735$
Vijayvergiya and Ghazzaly 2 (1973)	W_L, ρ_d	$\log \varepsilon_g = 0{,}055W_L + 0{,}0031\rho_d - 6{,}71$

Schneider and Poor (1974)	I_p, w_n	$\lg \varepsilon = \frac{3{,}87 * I_p}{w_n} - 1{,}19$

With these adjusted prediction models, we obtain swelling values summarized in Table 6.

Table 6: **Results obtained using corrected correlations**

Model	Seed et al. corrected	Nayak corrected	Vijayvergiya corrected	Vijayvergiya corrected	Schneider corrected
Maroua	8.8%	10.00%	11.22%	10.03%	10.22%
Classification	Swelling soil	Swelling soil	Swelling soil	Swelling soil	Swelling soil
Fotokol	9.97%	9.41%	8.00%	9.16%	8.50%
Classification	Swelling soil	Swelling soil	Swelling soil	Swelling soil	Swelling soil

Corrected correlations reveal that Maroua and Fotokol soils (Karal) are of swelling nature. Furthermore, identification test results also proved same. This is in line with results from a survey carried out by Djeddid Abdelkader et al (2001), who declares that parameters considered as the most crucial in the swelling behaviour of clays include the plasticity index, the percentage of clayey materials the blue methylene test value results and the shrinkage threshold. Therefore, it is advised rto use classifications based on several parameters in order to obtain a more reliable swelling prediction.

3.3 Relative variation of compounds swelling depending on the percentage of sand

Tables 7 to 9 and Figures 5 to 7 represent the swelling prediction depending on the percentage of sand; soils are referred to as:

- K1 : Soil from Maroua ;
- K2 : Soil from Fotokol.

Tableau 7: Relative swelling variation of compounds for a 10-stroke compacting depending on sand percentage

		Sand percentage					**Swelling reduction rate between 0**	**Average swelling reduction rate**
		0%	**10%**	**20%**	**30%**	**40%**		
Swelling at 10 strokes	K1 compound	14.10%	9.57%	7.95%	6.54%	5.98%	5.7%	6.0%
	K2 compound	16.67%	13.03%	11.88%	8.36%	6.07%	6.3%	

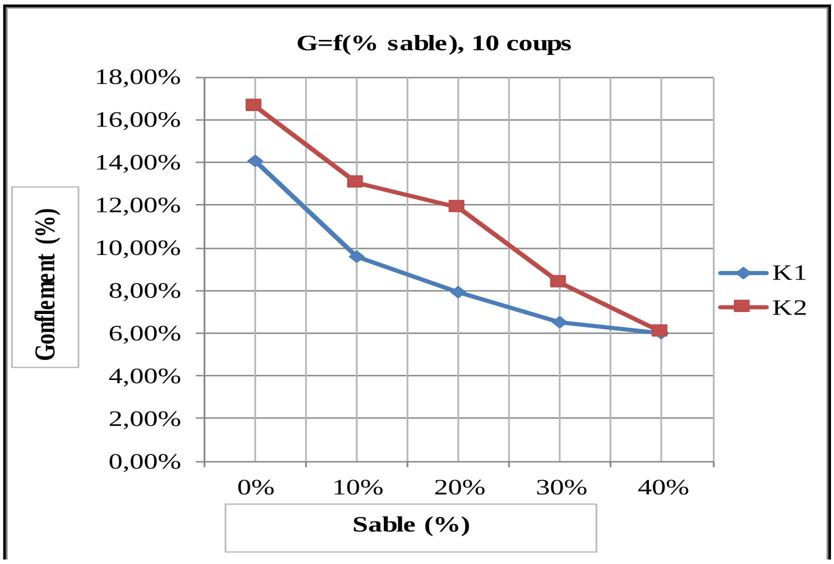

Figure 5: Relative swelling variation of the karal compounds for a 10-stroke compacting depending on sand percentage

Table 8: Relative swelling variation of the karal compounds for a 25-stroke compacting depending on sand percentage

		Sand percentage					**Swelling reduction rate between 0**	**Average swelling reduction rate**
		0%	**10%**	**20%**	**30%**	**40%**		
25-stroke swelling	K1 compound	11.97%	8.38%	6.92%	5.30%	4.96%	5.8%	5.85%
	K2 compound	12.35%	10.81%	9.40%	6.71%	5.04%	5.9%	

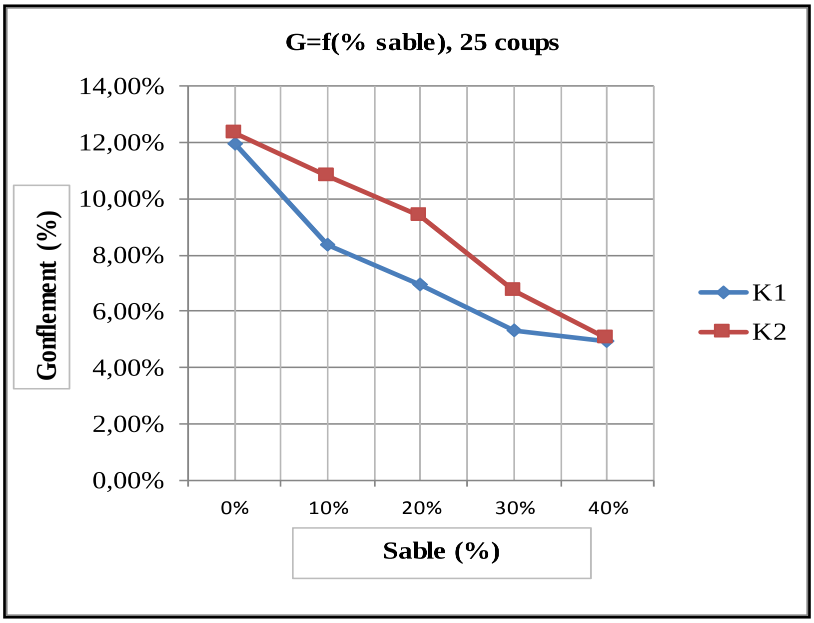

Figure 6: Relative swelling variation of the karal compound for a 25-stroke compacting depending on sand percentage

For a compacting corresponding to 25 strokes, figure 6 shows the swelling rate variation depending of the percentage of sand added. For materials without any addition of sand, we obtain swelling rates of 11.97% (Maroua) and 12.35% (Fotokol) respectively. For 40% of sans added, this rate moves to 4.96% (Maroua) and 5.04 (Fotokol) which makes a reduction rate of 7.01% and 7.31% respectively. It is noticed that at 25 strokes, swelling rates whose values of around 5% are interesting.

Table 9:Relative swelling variation of the karal compounds for a 55-stroke compacting depending on sand percentage

		Sand percentage					**Swelling reduction rate between 0 and 40%**	**Average swelling reduction rate between 0**
		0%	**10%**	**20%**	**30%**	**40%**		
55 strokeswelling	K1 compound	10.26%	7.05%	5.04%	4.36%	1.97%	5.74%	5.94%
	K2 compound	8.55%	8.36%	6.15%	5.68%	1.97%	6.14%	

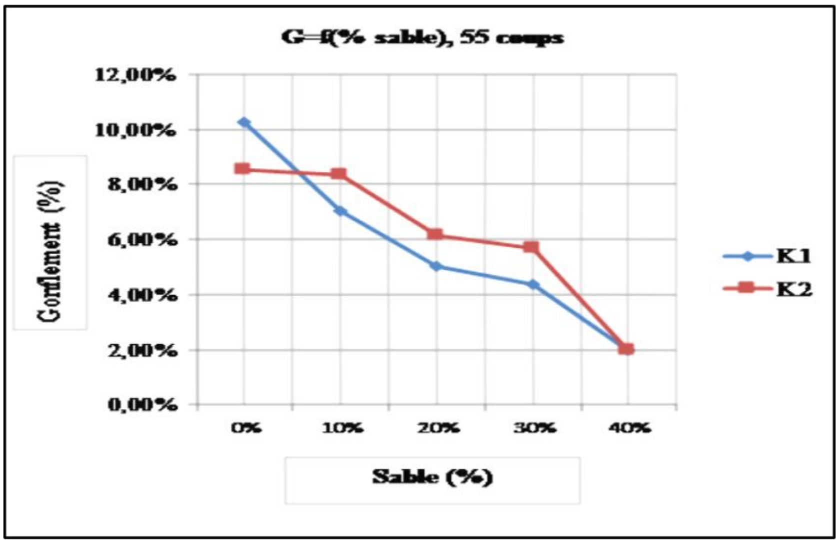

Figure 7: Relative swelling variation of the karal compounds for a 55-stroke compacting depending on sand percentage

For a compacting corresponding to 55 strokes, figure 7 shows the swelling rate variation depending on the percentage of sand added. For materials without any addition of sand, we obtain swelling rates of 10,26% (Maroua) and 8,55% (Fotokol) respectively. For 40% of sans added, this rate moves to 1,97% (Maroua) and 1,97 (Fotokol) which makes a reduction rate of 8,29% and 6,58%respectively. It is noticed that at 55 strokes, swelling rates stand at 1.97%. Therefore the mixture is non swelling. We also notice that both soils have very close swelling rates with a slightly higher value for the Fotokol soil.

Table 10: Relative swelling variation for the K1 karal from Maroua depending on sand percentage

		Sand percentage				
	Number of strokes	**0%**	**10%**	**20%**	**30%**	**40%**
K1 relative swelling (Maroua)	10	14.10%	9.57%	7.95%	6.54%	5.98%
	25	11.97%	8.38%	6.92%	5.30%	4.96%
	55	10.26%	7.05%	5.04%	4.36%	1.97%

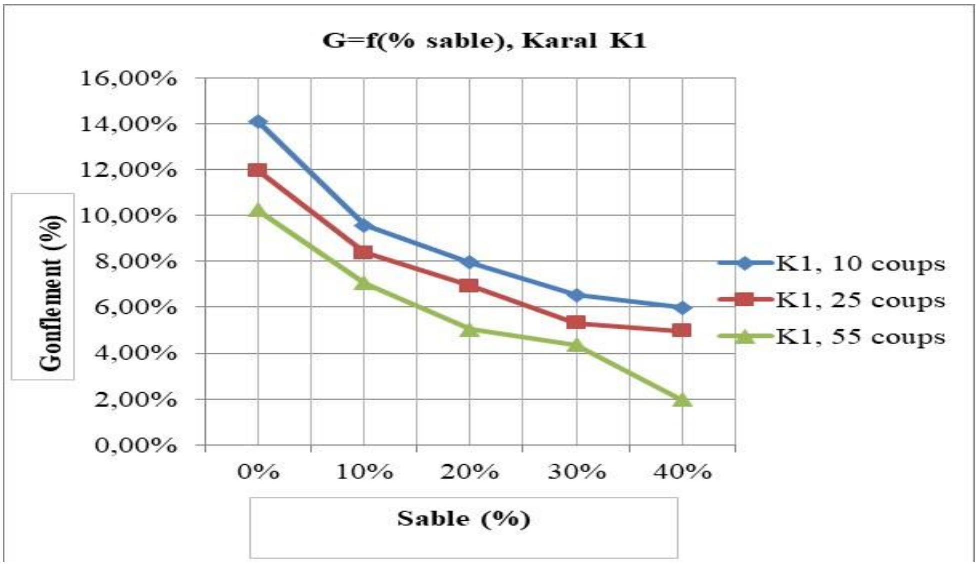

Figure 8: Relative swelling variation for the K1 karal compounds from Maroua depending on sand percentage.

Table 11: Relative swelling variation for the K2 karal compounds from Fotokol depending on sand percentage.

		Sand percentage				
	Number of stokes	**0%**	**10%**	**20%**	**30%**	**40%**
K2 relative swelling (Fotokol)	10	16.67%	13.03%	11.88%	8.36%	6.07%
	25	12.35%	10.81%	9.40%	6.71%	5.04%
	55	8.55%	8.36%	6.15%	5.68%	1.97%

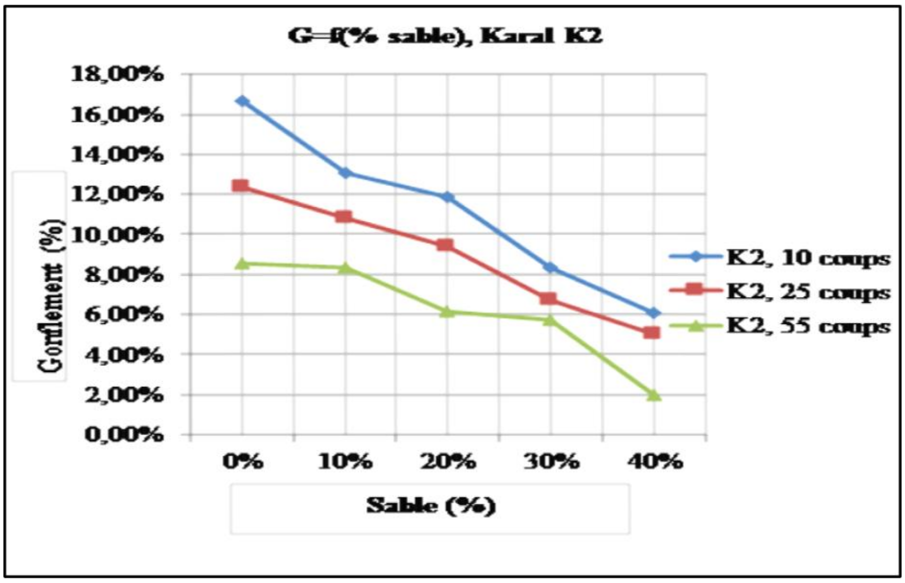

Figure 9: Relative swelling variation for the K2 karal compounds from Fotokol depending on sand percentage.

Swelling results after 4 days of saturation which are summarized in Tables 7 to 11 and Figures 5 to 9 show that:

- The swelling rates for the Karal from Maroua (K1) and Fotokol (K2) reduce as the compacting power (or the number of strokes) increases ;

- For non stabilized karal and when the number of strokes increases from 10 to 55, the swelling rate moves from 14.10% to 10.26% for the Maroua karal (K1) and from 16.67% to 8.55% for that from Fotokol (K2). The highest reduction in the swelling rate of 1.97% is reached when the sand percentage in the compound is 40%.

If we take the swelling rate of the karal without any addition of sand for a 55 stroke compacting as reference, we move from 10.26% to 1.97% for the Maroua Karal (K1) and from 8.55% to 1.97% for the Fotokol karal (K2). Reduction rate is 8.29% (K1) and 6.58% (K2) respectively, giving an average of 7.44%.

Results analyses of swelling tests after 4 days of saturation depending on the percentage of sand added in compounds show a reduction in the swelling rate when the percentage of sand increases.

These results are corroborated by works carried out by Mouroux P. (1969), Didier G. (1972), Kaoua et al. (1994), Bengraa et al. (2005), and Hachichi et al. (2009).

In final analysis, on the basis of results above, we can say that the addition of sand in the Maroua and Fotokol soils improves the performance of compounds as far as the swelling rate is considered (reduction of the latter when the sand rate increases).

IV. CONCLUSIONS

This article aims at stabilizing swelling soils through the addition of sand. The study confirmed the swelling nature of soils used in the survey. However, it should be noted that the use of mathematical models proposed in literature are not all applicable to all clays. These models were adjusted to show the swelling nature of soils analyzed.

The study carried out on performance tests of sand-lithostabilized soils revealed us the swelling rate reduces when the percentage of sand added in compounds increases.This reduction is significant for a 40% percentage of the mass of stabilized soil. It revealed the importance of sand as stabilizing material for swelling soil. This conclusion was confirmed by other scientists who carried out similar surveys..

In perspective, given the geological variability of soils (karal) in the Far-North Region of Cameroon, we intend to extend our study to other sites in the region so as to develop a geotechnical database which, in the long run, will help engineers to better lay out their construction projects.

BIBLIOGRAPHY

[1]. F. H. Chen : Fondation on expansive soils. Elsevier Ed. 1988

[2]. Hachichi A., Souad Amel B. M. Benaissa A.et Jean Marie Fleureau (2009). Etudes des phénomènes retrait-gonflement et stabilisation des sols gonflants de la région d'Oran.

[3]. Mouroux P. (1969). Contribution à l'étude des problèmes de retrait et de gonflement des sols. Grade Docteur de spécialité, Soutenu 1969, Faculté des Sciences de l'Université de GRENOBLE.

[4]. Didier G. (1972). Gonflement cristallin et microscopique des montmorillonites. Thèse pour l'obtention du titre de docteur-Ingénieur, Université Claude Bernard, France

[5]. Kaoua F., derriche Z., Laradi N. (1994) : Contribution à l'étude de la stabilisation des sols gonflants par ajout de sable. Revue technique de l'ecole Nationale des Travaux Publics, Algétie Equipement, n°15.

[6]. Bengraa L. Hachichi A., Bourokba S., Benaissa A. (2005) : Etude de la stabilisation des argiles gonflantes par ajout de sable. 2e journée d'études sur les sols gonflants. Tlemcen (Algérie).

[7]. Jean Francois Serratrice, Bertrand Soyez (1996) : les essais de gonflement. Bulletin des laboratoires des Ponts et Chaussées – 204 – Juillet-Août 1996 – Réf. 4082 – PP 65-85

[8]. Zohra Derriche, Mustapha Kebaili (1998) : Prévision du gonflement des argiles d'In-Aménas. Bulletin des laboratoires des Ponts et Chaussées – 218 – Novembre-Décembre 1998 – Réf. 3865 – PP 15-23

[9]. Djeddid Abdelkader, Aissa Mamoune Sidi Mohammed (2001): Identification et prévision du gonflement de quelques sols de la region de Tlemcen (Algérie).

[10]. Ali El Yaakoubi, Saida Ahyoud, Adel asselman (2014): Nouveau modèle empirique du gonflement libre des sols argileux

[11]. Gérard Bigot, Moulay Idriss Zerhouni (2000): Retrait, gonflement et tassement des sols fins. Bulletin des laboratoires des Ponts et Chaussées – 229 – Novembre-Décembre 2000 – NT 4252 – PP 105-114

[12]. M. Lamara, M. K. Gueddouda, B. Benabed (2006) : Stabilisation physico-chimique des sols gonflants (sable de dune+sel). Revue Française de géotechnique N°115, 2e trimestre 2006

[13]. Institut des Sciences et des techniques de l'équipement et de l'environnement pour le développement (1988) : Sols argileux gonflants, Site expérimental de Waza-Maltam ; rapport de synthèse. ISBN 2 86 815 031-4

[14]. Millogo Y. (2008). Etude géotechnique, chimique et minéralogique des matières premières argileuse et latéritique du Burkina Faso améliorées aux liants hydrauliques : application au génie civil (bâtiment et route). Th. Doc. D'Etat. Univ. Ouagadougou, 9-87p.

[15]. Seed H. B. & al (1988). Prediction of swelling potential for compacted clay. Journey of the soil mechanic and found. Div. ASCE, 88, n°SM4, pp. 107-131.