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Review Article

GEOTECHNICAL APPLICATION OF THE ALTEROLOGY OF AN EFFUSIF ROCK AND A FOUNDATION ROCKS IN THE LOWER AREA OF THE SOUTHERN SIDE OF BAMBOUTO MOUNTAINS (WEST CAMEROON)

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ABSTRACT
This article is the geotechnical study of the products of the alteration of the rocks of the lower area of the southern side of the Bambouto mountains. It has three main objectives: (1) The use and promotion of the products of alteration as part of an alternative in the construction industry in this modern world, (2) characterization of these products in road geotechnics and (3) the geotechnical characterization correlations (models) through lithology in its natural context. Based on the combination of an analysis of properties of compressed earth bricks stabilized or cooked, identification tests, lift and resistance tests of treated or not laterites, based on a correlation between altérologic parameters, the following results were obtained: (1) cooked BTC (950 ° C) resulting from the weathering products of trachybasalt have hyper mega resistance, stabilized BTC with lime (6%) from the products of alteration of the orthogneiss exhibit high resistance; (2) the sandy and clay lateritic soils derived from weathering of anatexite treated with 4% lime are used in subgrade and subbase, base layer when treated with 5% lime; the gravelly clay lateritic soils derived from the weathering of orthogneiss can be used naturally in subgrade, treated with 4% cement they can be used in sub-base, treated with 6% cement they are used in base layer; (3) four established arithmetic models allow the simple reading of geotechnical capabilities of profiles of alteration of any rock in its natural context.

Keywords: *Geotechnical Application, Rock, Weathring Products, Arithmetic Models*

INTRODUCTION
Today, most of the developing countries face an ever growing problem: provide enough adequate and accessible housing to its population. Given the population and area size of Cameroon, the road density is 3 km of roads per 1,000 inhabitants and 107 km of roads per 1,000 square kilometers (Ngoumbe and Ekwalla, 2004). Of the 50,000 km of roads that Cameroon has, 28,000 km are priority roads, that is to say have a periodic routine maintenance. But only 45% of paved roads and 55% of dirt roads are of a satisfactory quality (AfDB / OECD, 2006). Today development projects promote the optimal use of local materials (rocks, soils and geo-materials of anthropogenic origin) in our building works. The advantage of using these local materials is that they are not expensive and accessible to many people.
This study focuses on the geotechnical application of Alterology of an effusive rock and a group of three rocks forming the base complex in the lower area of the southern side of the Bambouto mountains (West Cameroon). "The quality of human works (roads and buildings ...) depends both on the materials (soil, aggregates, lime, cement, etc) used and the working environment. Thus, an assumption can be made by connecting the strength and durability of the structures to the soil characteristics: (1) the origin and nature of the soil, (2) the altérologic parameters and (3) the environment for implementation. In the event where any of these parameters is not met, the building suffers from many diseases: withdrawal and drying of the masonry component; faïençages, rutting, phenomena of "corrugated iron" and "gravel loss" (loss of material) for roads particularly in ground.
Four locations were selected because of their lithological feature. Batsingla, Fomopéa, Fontsa-Touala and Litakli villages respectively with soils developed on basalt, migmatic complex, biotite gneiss and anatexite. Wells have been darkened and profiles described. Samples of rock and soil were collected for

mineralogical analysis, geochemical tests, microscopic observation, manufacture of compressed earth bricks and related mechanical and physical testing, identification tests and bearing capacity of soils, soil treatment with lime and cement. The data obtained with the interpretation of the results are correlated to propose alterological-geotechnical models.

This study is organized into four parts. It begins with the correlation context (I), goes through the construction of the model (II) and the arithmetic model (III), to end with a sample reading (IV)

Data Consolidation: Background of Correlation

The first work of this correlative study is to synthesize existing knowledge and results on the geology of the site. The different elements considered consist of: geological formation (1st), age (2nd), topography (3rd), climate (4th), mineral and geochemical Association (5th), mechanical and physical quality of geotechnical product (6th)

The choice of model is based on the combination of these various elements in the various studied sites thus defining the context of correlation shown in Table 1.

Table 1: Background of the correlation

Element	Model 1	Model II	Model III	Model IV
Rocks	Trachy-Basalt (BT)	Granitoïds (FP)	Ortogneiss (FT)	Anatexite (LT)
Age (MA)	52 to 38	660 to 580	660 to 580	660 to580
Topography	Hills in half orange, with higthly slope and talweg in U form	Sharp on top, narrow talweg and rocky escarpment	Sharp on top and narrow talweg	Convex and concave Versants with higthly slope
Climate	1830 mm en moyenne /an ; 14,8 °C à 25 °C			
mineral and geochemical Association	Min-Ox-I	Min-Ox-II	Min-Ox-III	Min-Ox-IV

In the Table 1, the different mineral and geochemical associations correspond to mineral and geochemical characteristics of the studied soil profiles at higher or equal to 10 m depths at the different sites: BT for Batsingla, FP for Fomopéa, FT for Fontsa Touala and LT for Litakli. The parameters Min. and Ox. Are abbreviations of minerals and oxides. Thus the various terms are defined as follows:

- Min-Ox-I mean "mineral and oxides association comparable to those of Batsingla site ";
- Min-Ox-II means "mineral and oxides association comparable to those of Fomopéa site ";
- Min-Ox-III means "mineral and oxides association comparable to those of Fontsa-Touala site ";
- Min-Ox-IV means "mineral and oxides association comparable to those of Litakli site ".

These different combinations are shown in Tables 2, 3, 4 and 5.

Model Building

One of the difficulties of the geometric representation of the mechanical strength of the soil "from alteration" of rocks is related to the high spatial variability of surface formations.

It is necessary to integrate geological rules governing their implementation in view to control their interpolation (Bourgine *et al.*, 2006; Dominica, 2007).

The nature of weathering processes (mechanical alteration, chemical alteration), tectonics (brittle, soft), the age of rocks (recent formations, Precambrian formation), climate (precipitation, temperature), topography (slope, valley, escarpment) should also be considered, as the soil depth.

Moreover it is necessary to estimate the local reliability of the model in order that it can be used, for example, by decision-makers as part of major development operations (Dominique, 2007).

Table 2: Mineral associations, oxides and trace elements of model I

%	**Maximum**	**Minimum**	**Average**	**Standard deviation**	**ppm**	**Maximum**	**Minimum**	**Average**	**Standard deviation**
SiO_2	32,56	0,43	12,64	14,22	**As**	115,78	10,79	65,23	44,70
TiO_2	8,38	2,62	5,99	2,57	**Cu**	52,34	2,00	34,24	22,49
Al_2O_3	43,71	12,53	27,64	12,99	**Ga**	54,87	23,28	43,55	14,55
Fe_2O_3	67,26	18,25	39,36	21,42	**Mo**	15,70	3,22	8,72	5,75
MnO	0,11	0,05	0,07	0,02	**Nb**	163,71	50,98	111,44	47,50
MgO	0,53	0,00	0,23	0,22	**Ni**	60,56	4,71	33,40	23,34
CaO	0,00	0,00	0,00	0,00	**Pb**	32,83	16,68	24,06	6,66
Na_2O	0,01	0,00	0,01	0,00	**Rb**	16,64	4,08	9,62	5,63
K_2O	0,02	0,00	0,01	0,01	**Sr**	89,48	21,95	52,85	31,63
P_2O_5	0,66	0,26	0,46	0,23	**Th**	35,43	15,04	25,39	9,70
H_2O	20,35	12,15	15,33	3,51	**U**	40,14	7,16	21,21	15,74
-					**W***	12,34	6,00	8,36	2,75
					Y	34,19	10,59	24,62	9,97
					Zn	124,61	45,46	72,85	35,29
					Zr	858,06	273,28	577,90	240,49
					Cl*	7,58	7,58	7,58	0,00
					Co	47,21	8,42	21,38	17,51
Minerals	**Maximum**	**Minimum**	**Average**	**Standard deviation**	**Cr**	895,04	202,01	546,14	347,61
					F*	4709,61	100,00	1785,93	2193,44
Gibbsite	60,89	10,22	22,30	27,27	**S***	43,95	16,00	23,49	13,67
Kaolinite	86,92	5,63	26,75	44,61	**Sc**	66,42	33,09	49,51	13,61
Quartz	0,7	0,18	0,22	0,37	**V**	770,49	517,47	645,98	115,88
Anatase	9,1	3,1	4,75	3,03	**Cs**	9,43	9,43	9,43	0,00
Goethite	84,15	18,09	40,56	33,43	**Ba**	4,48	4,48	4,48	0,00
Hematite	12,93	12,93	3,23		**La**	4,26	4,26	4,26	0,00
Magnetite	4,81	3,98	2,20	0,59	**Ce**	149,04	4,88	84,05	60,51

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Table 3: Mineral associations, oxides and trace elements of model II

%	**Maximum**	**Minimum**	**Average**	**Standard deviation**	**ppm**	**Maximum**	**Minimum**	**Average**	**Standard deviation**
SiO_2	64,51	55,51	59,70	4,082	**As**	28,12	3,00	15,22	14,12
TiO_2	2,09	0,72	1,16	0,629	**Cu**	36,99	2,00	14,83	16,66
Al_2O_3	21,59	14,83	18,25	2,993	**Ga**	28,83	2,00	14,89	14,91
Fe_2O_3	12,05	5,30	7,65	3,133	**Mo**	1,00	1,00	1,00	0,00
MnO	0,14	0,03	0,08	0,044	**Nb**	14,83	2,00	7,74	6,72
MgO	5,10	0,53	2,21	1,991	**Ni**	35,04	3,00	15,35	14,98
CaO	1,93	0,00	0,48	0,963	**Pb**	36,68	3,00	15,24	16,01
Na_2O	1,80	0,01	0,46	0,896	**Rb**	150,17	2,00	71,77	80,87
K_2O	6,12	2,35	4,19	1,565	**Sr**	336,18	55,83	193,90	114,48
P_2O_5	0,18	0,03	0,08	0,066	**Th**	22,10	3,00	11,23	9,74
H_2O	8,37	3,65	5,83	2,134	**U**	3,00	3,00	3,00	0,00
-					**W***	210,16	71,14	138,50	63,81
					Y	14,94	3,45	9,15	6,27
					Zn	74,93	11,98	41,73	34,24
					Zr	312,02	12,92	127,14	143,70
					Cl*	7,58	7,58	7,58	0,00
Minerals	**Maximum**	**Minimum**	**Average**	**Standard deviation**	**Co**	1146,07	21,60	513,39	555,91
					Cr	81,58	6,84	45,15	33,25
Kaolinite	31,83	8,6	15,63	11,67	**F***	140,29	100,00	110,07	20,14
Quartz	40,4	21,38	30,33	8,03	**S***	17240,07	16,00	8296,91	9577,25
Magnetite	1,93	1,93	0,48	-	**Sc**	14,42	1,51	7,01	5,62
Muscovite	15,25	7,5	10,56	3,64	**V**	134,67	16,81	67,41	59,99
Biotite	34,8	10,87	11,42	16,92	**Cs**	109,31	54,56	83,77	25,72
Plagioclase	11,51	11,51	2,88	-	**Ba**	4331,31	453,85	2785,05	1860,83
Microcline	36,96	9,9	27,87	12,75	**La**	142,90	16,37	65,54	56,02
Actinolite	3,29	3,29	0,82		**Ce**	216,80	49,64	112,75	76,40

Table 4: Mineral associations, oxides and trace elements of model III

%	**Maximun**	**Minimun**	**Average**	**Standard deviation**	**ppm**	**Maximum**	**Minimum**	**Average**	**Standard deviation**
SiO_2	64,74	60,21	64,74	17,95	**As**	23,61	23,61	23,61	-
TiO_2	0,42	0,01	0,42	0,28	**Cu**	5,15	5,15	5,15	-
Al_2O_3	21,00	0,01	21,00	11,29	**Ga**	25,82	25,82	25,82	-
Fe_2O_3	3,44	0,02	3,44	1,97	**Mo**	1,00	1,00	1,00	-
MnO	0,01	0,00	0,01	0,02	**Nb**	15,57	15,57	15,57	-
MgO	0,08	0,00	0,08	0,16	**Ni**	21,32	21,32	21,32	-
CaO	0,00	0,00	0,00	0,55	**Pb**	31,19	31,19	31,19	-
Na_2O	0,01	0,01	0,01	1,52	**Rb**	8,25	8,25	8,25	-
K_2O	0,12	0,00	0,12	2,21	**Sr**	5,99	5,99	5,99	-
P_2O_5	0,03	0,00	0,03	0,03	**Th**	3,00	3,00	3,00	-
H_2O	9,59	0,18	9,59	4,99	**U**	3,00	3,00	3,00	-
-					**W***	476,62	476,62	476,62	-
					Y	5,82	5,82	5,82	-
					Zn	30,07	30,07	30,07	-
					Zr	176,75	176,75	176,75	-
					Cl*	7,58	7,58	7,58	-
					Co	114,89	114,89	114,89	-
					Cr	49,76	49,76	49,76	-
					F*	100,00	100,00	100,00	-
					S*	16,00	16,00	16,00	-
					Sc	7,49	7,49	7,49	-
Minerals	**Maximum**	**Minimum**	**Average**	**Standard deviation**	**V**	69,76	69,76	69,76	-
					Cs	51,84	51,84	51,84	-
Quartz	47,56	47,56	47,56	-	**Ba**	50,77	50,77	50,77	-
kaolinite	43,07	43,07	43,07	-	**La**	29,92	29,92	29,92	-
Gibbsite	9,37	9,37	9,37	-	**Ce**	106,01	106,01	106,01	-

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Table 5: Mineral associations, oxides and trace elements of model IV

%	**Maximum**	**Minimum**	**Average**	**Standard deviation**	**ppm**	**Maximum**	**Minimum**	**Average**	**Standard deviation**
SiO_2	68,25	59,58	63,91	6,13	**As**	27,33	3,00	15,16	17,20
TiO_2	1,45	0,80	1,13	0,46	**Cu**	12,47	2,00	7,23	7,40
Al_2O_3	19,02	15,50	17,26	2,49	**Ga**	21,11	2,00	11,55	13,51
Fe_2O_3	10,56	6,31	8,43	3,01	**Mo**	1,00	1,00	1,00	0,00
MnO	0,04	0,02	0,03	0,01	**Nb**	23,25	2,00	12,62	15,03
MgO	0,05	0,03	0,04	0,01	**Ni**	24,92	3,00	13,96	15,50
CaO	0,00	0,00	0,00	0,00	**Pb**	15,52	3,00	9,26	8,85
Na_2O	0,01	0,01	0,01	0,00	**Rb**	7,34	2,00	4,67	3,77
K_2O	0,14	0,03	0,08	0,08	**Sr**	214,24	3,00	108,62	149,37
P_2O_5	0,12	0,04	0,08	0,06	**Th**	3,00	3,00	3,00	0,00
H_2O	9,35	7,98	8,67	0,97	**U**	3,00	3,00	3,00	0,00
-					**W***	460,86	56,35	258,60	286,03
					Y	9,48	3,84	6,66	3,99
					Zn	21,89	13,40	17,64	6,01
					Zr	208,78	10,00	109,39	140,56
					Cl*	7,58	7,58	7,58	0,00
					Co	389,38	145,31	267,35	172,58
					Cr	128,61	6,84	67,73	86,11
					F*	606,08	100,00	353,04	357,85
					S*	20162,36	16,00	10089,18	14245,63
Minerals	**Maximum**	**Minimum**	**Average**	**Standard deviation**	**Sc**	15,05	1,49	8,27	9,58
					V	140,48	16,81	78,64	87,45
Gibbsite	23,47	21,25	22,36	1,57	**Cs**	125,17	49,81	87,49	53,29
Kaolinite	26,3	18,56	22,43	5,47	**Ba**	4815,67	54,38	2435,02	3366,74
Quartz	54,54	52,47	53,51	1,46	**La**	20,61	9,03	14,82	8,19
Hématite	3,43	3,43	1,715	-	**Ce**	84,69	59,83	72,26	17,58

Evaluation of BTC Potential

Compressed Bricks Earth (BTC) cooked (950, 1050 or 1100 ° C) or stabilized (at 2, 4, 6 and 8% lime or cement) manufactured with commodity clay of different sites were tested. Due to their mechanical and physical values , the database used to construct the geology-Masonry correlation has been designed. Capacities are shown in Table 6 according to different models.

Table 6: Mechanical and physical capabilities of BTC of various models

BTC compression résistance (MPa) of various models				
Types of BTC	**Model I**	**Model II**	**Model III**	**Model IV**
0	1,65	0,16	0,63	1,81
Cm2	1,52	3,06	4	2,69
Cm4	2,32	3,31	4,88	3,06
Cm6	2,74	3,44	5,5	4,25
Cm8	3,05	4,06	5,94	5,13
Ch2	2,01	0,17	2,81	2,06
Ch4	2,32	3,19	2,94	3,31
Ch6	2,93	5,06	6,88	5,5
Ch8	3,54	6,31	8,44	5,88
950°C	10,59	4,25	5,94	1,19
1050°C	13,51	4,88	6,56	3,75
1100°C	33,78	7,06	7,63	4,13
BTC Water amount per cent absorption of various models				
Types of BTC	**Model I**	**Model II**	**Model III**	**Model IV**
0	-	-	-	-
Cm2	-	18,5	19,3	17,6
Cm4	38,8	17,2	19	17
Cm6	37,6	15,5	18,6	16,9
Cm8	37,1	16,1	18,2	16,7
Ch2	-	-	-	17,8
Ch4		18,1	17,4	17,6
Ch6	38,5	17,4	17	16,4
Ch8	38,1	17,1	16,3	16,3
950°C	40	21,8	22,4	26,7
1050°C	39,7	21,3	22,1	25,5
1100°C	38,6	21	22,1	25
Masse volumique (g/cm^3) des BTC des différents modèles				
Types de BTC	**Modèle I**	**Modèle II**	**Modèle III**	**Modèle IV**
0	1,742	1,903	2,003	2,024
Cm2	1,611	1,888	1,991	1,948
Cm4	1,655	1,917	1,974	1,977
Cm6	1,687	1,903	1,974	1,96
Cm8	1,687	1,875	1,991	1,96
Ch2	1,673	1,861	1,962	1,994
Ch4	1,673	1,889	1,989	2,009
Ch6	1,616	1,875	2,003	1,989
Ch8	1,69	1,888	1,989	1,989
950°C	1,499	1,788	1,73	1,672
1050°C	1,461	1,773	1,73	1,705
1100°C	1,561	1,788	1,73	1,719

***N.B :** 0 = BTC non traité, Cmx = BTC traité à x% de ciment, Chx = BTC traité à x% de chaux*
y°C = BTC cuite à y°C

Evaluation of the Potentials of Raw Materials from Clay Origin, and Lateritic Origin for Pavement Layers

Among the soils of the different study sites, those of Batsingla and Litakli are from clay and lateritic origin. For this reasons, these two soils were selected to perform Geological - Geotechnical correlations in terms of pavement layers. Batsingla soils enter in the model I and are following the HRB soil classification A-2-7 (2); while Litakli soils inter in the Model IV and following Class-A 7-5 (0-12). The following table shows the bearing capacity of soil according to these models.

Table 7: Bearing capacity of soils following models

N°	Model I	Model IV
A-0	43	18
A-C-2-4	43	30
A-C-2-7	74	55
A-C-2-14	94	80
A-C-4-4	90	42
A-C-4-7	126	60
A-C-4-14	153	80
A-C-6-4	108	35
A-C-6-7	133	55
A-C-6-14	163	72
A-Cx-2-4	60	53
A-Cx-2-7	82	72
A-Cx-2-14	94	92
A-Cx-4-4	90	92
A-Cx-4-7	126	113
A-Cx-4-14	153	133
A-Cx-6-4	82	70
A-Cx-6-7	140	100
A-Cx-6-14	180	135

N.B *C = cement, Cx = lime, A = clay soil.* ***e.g:*** *A-0 = naturally clay soil,*

A-C-2-4: Clay soil treated with 2% cement after 4 immersion days,

A-Cx-6-14: Clay soil treated with 6% lime after 10 days curing in air, and 4 immersion days.

Geology-Geotechnics Correlation: Arithmetical Model

Geotechnical data obtained are represented on 3D stacked areas for various models. This allows a simple reading of geotechnical capabilities of the profiles of alteration of any rock depending on its natural context.

These geotechnical capabilities are grouped into production capability of single or treated BTC and soil lift as pavement layers (sub grade, sub base and base layer).

Production Capability of BTC

The following figures show the mechanical and physical skills that different defined models have.

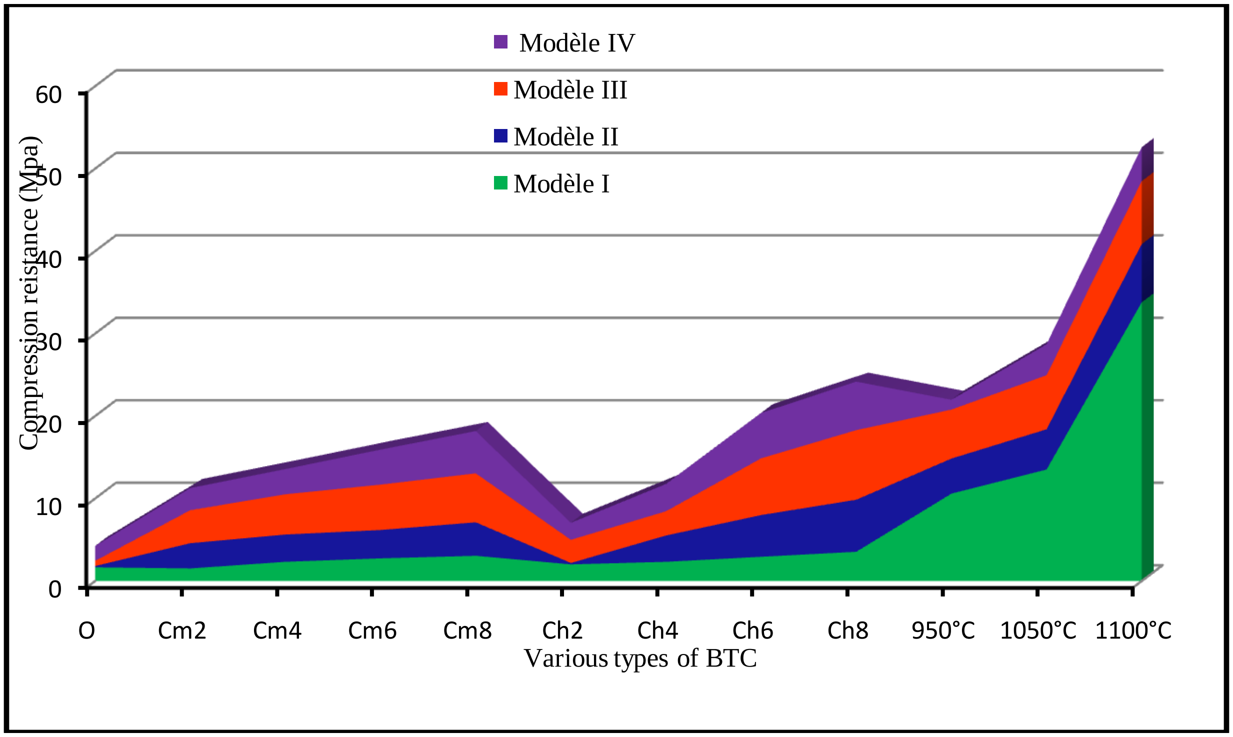

Figure 1: Compression resistance of BTC for variuos model

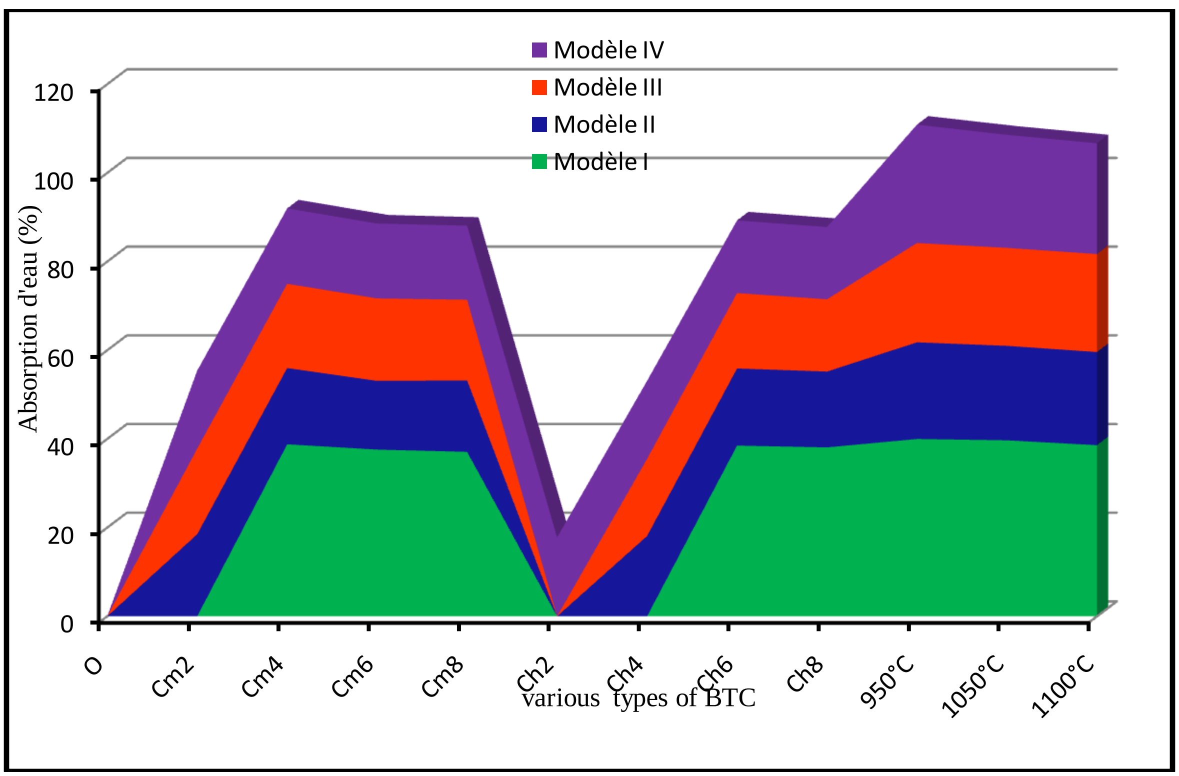

Figure 2: Water absorption of BTC of the various models

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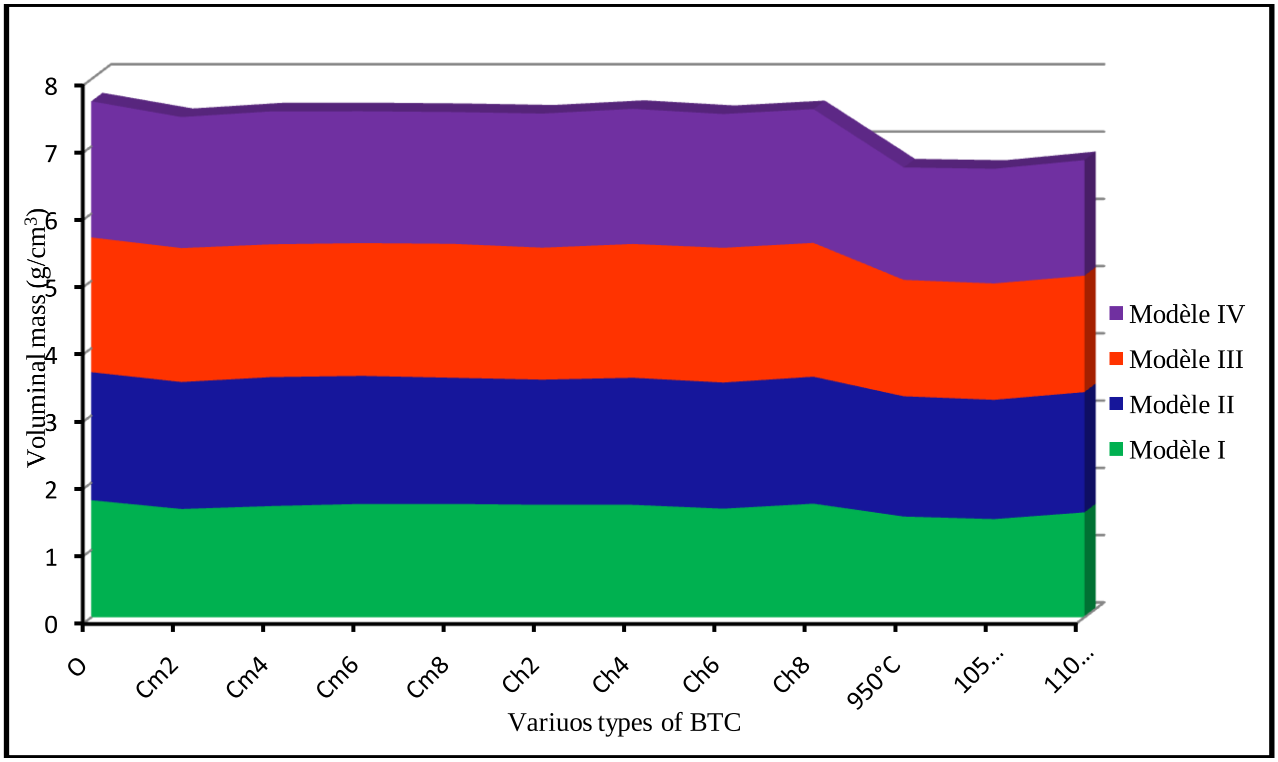

Figure 3: Voluminal mass of BTC of the various models

Production Capability of Soils Use in Pavement Layers

The following figures show the punching resistance that different defined models have.

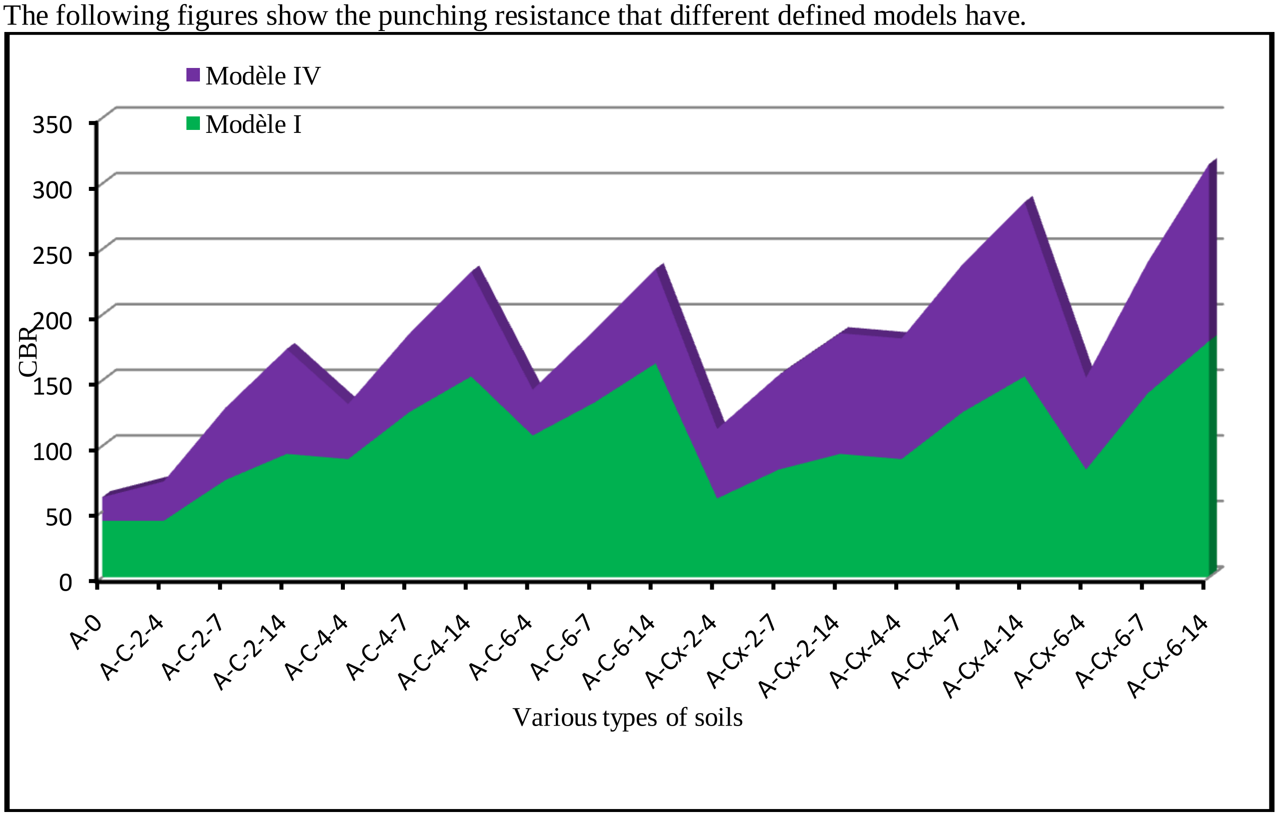

Figure 4: Soils lift of the various models

Sample Reading

Terms of a Problem

The Ministry of Public Works intends to build a ground road to connect two locations in an environment characterized by hills in a half-orange steep slope and U-thalweg. Hydrological research shows that annual average rainfall is 1830 mm and temperatures range from 14.5 ° C to 25 ° C. Previous geological studies show that the area is made of trachybasalt. The Ministry wishes to know within a very limited time period the possibility of using local materials.

Answers

These elements characterize the models I.

Reading of figure 4 shows that soils derived from the alteration of trachybasalts in this environment have a lift of at least 40 % According to the sizing guide of roads in tropical countries, they may be used:

- in layer form, when dosed at 2% of lime or cement (CBR > 30 %);
- in sub base, when dosed at 2 % of lime ($CBR_{95\%OPM}$ after 4 days of treatment with water $>$ 60 %.) or 4 % of cement ($CBR_{95\%OPM}$ after 3 days of treatment with air and 4 days of treatment with water $>$ 100 %);
- in base layer, when treated with 6% of lime or cement ($CBR_{95\%OPM}$ after 3 days of treatment with air and 4 days of treatment with water $>$ 160%.
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CONCLUSION

The objective of this study as defined at the beginning of this article was to show the best combinations between the geotechnical features of a soil and the alterological settings for an easier use of geo-materials in human structures. The combined use of mineralogical / geochemical data and mechanical/physical data of BTC on one part and those of the soils on the other part have helped to release four correlation models of geological/geotechnical data:

- Model I is associated to an environment developed on recent trachy-basalts, hill in half-orange form with steep slope and U-trough, average precipitation per year of 1830 mm and temperature between 14.8 ° C and 25 ° C.
- Model II is associated to an environment developed on granitoïd, pointed tip and narrow trough, rocky cliff, average precipitation per year of 1830 mm and temperature between 14.8 ° C and 25 ° C.
- Model III is associated to an environment developed on orthogneis, pointed tip and narrow trough, with average precipitation per year of 1830 mm and temperature between 14.8 ° C and 25 ° C.
- Model IV is associated to an environment developed on anatexites, convexo-concave side, steep slopes, average precipitation per year of 1830 mm and temperature between 14.8 ° C to 25 ° C.

These models give answers to some of the most frequently asked questions in construction projects.

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