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RESEARCH ARTICLE

LITHO STABILIZATION OF THE LATERITIC GRAVELLY BY GRANITE CRUSHED FOR THEIR USE IN FLEXIBLE PAVEMENT IN BENIN

Babaliye Olivier[1], Dr. Houanou Kocouvi Agapi[1], Prof Vianou Antoine[2], Prof Tchehouali Adolphe[1] and Prof Foudjet Amos Erick[3]

1. Laboratoire d'Energétique et de Mécanique Appliquée- Ecole Polytechnique d'Abomey-Calavi, Université d'Abomey-Calavi, Bénin.
2. Laboratoire de Caractérisation Thermophysique des Matériaux et d'Appropriation Energétique, Université d'Abomey-Calavi, Bénin.
3. CRESA Forêt-Bois, Faculté d'Agronomie et des Sciences Agricoles, Université de Dschang, Cameroun.

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Abstract

This study shows the improvement of laterite from Benin whose borrowing is abandoned with class 0/31.5 granite crushed stone for its use in road construction according to the rules of CEBTP of 1972, revised in 1984. The validation of this method called litho stabilization was carried out by determining the cohesion and the internal friction angle. The results of the mixes 35% crushed + 65% laterite and 40% crushed + 65% laterite meet the criteria of CEBTP, 1984 for the foundation layer of flexible pavements. We carried out the direct shear test on natural laterite and the two mixtures used as a foundation layer for flexible pavements in order to identify the best mix. On the one hand the 35% crushed mixture plus 65% laterite gave: 26.46 KPa of cohesion and 30.30 of internal friction angle at 100% OPM, on the other hand the 40% crushed mixture plus 60% laterite gave: 4.75 Cohesion KPa and 27.420 internal friction angle at 100% OPM. All these properties are superior to that of natural laterite except the cohesion of the 40% crushed mixture. This confirms that the addition of crushed stone makes the laterite rigid and dense.

Introduction:-

The well-constructed road is the development of a country, it ensures the movement of people and goods. Note that the majority of roads in developing countries, in particular in Benin [3; 10] are built with good quality lateritic gravelly, given its abundance and lower operating costs. We note today in Benin, an exponential increase in the construction of road infrastructure, this is due to the different asphalting and paving works that the government has launched in the country. This directly affects the use of good quality gravelly soils. If these good quality materials are far from road projects, it affects the cost of the realization.

In addition, the technique for improving the natural lateritic gravels that we use in Benin is stabilization with cement. According to Ndiaye, N.D., 1996 [12] the mixture of lateritic gravelly and cement poses problems as well as the implementation. In addition, cement is expensive today, making it difficult for developing countries to bear the costs of road projects.

Corresponding Author:- Babaliye Olivier
Address:- Laboratoire d'Energétique et de Mécanique Appliquée- Ecole Polytechnique d'Abomey-Calavi, Université d'Abomey-Calavi, Bénin.

Indeed, the various previous studies carried out on the litho-stabilization of the lateritic gravelly with crushed stone have not been the subject of the mechanical parameters (cohesion and internal friction angle) of the mixture but only deal with the geotechnical properties some mixture [2; 7; 8; 13; 15].

Methods and Materials:-

Geotechnical and mechanical characteristic of natural lateritic gravelly and crushed granite

The litho-stabilization technique consists in adding to the poor natural lateritic grit of good quality granite crushed material until there is a high-performance material that meets the criteria for use in a bedding layer. We characterized the natural lateritic gravelly, the granite crushed and the mixture then followed by direct shear test on the natural gravelly (class 0/5) and the mixture (s) (class 0/5) meeting the criteria from CEBTP, 1984. Note that this part is more deformed and its results are representative [14].

The natural lateritic gravel and the mixtures were characterized by the tests: particle size analysis (NF P 94-056); limit of Atterberg (NF P 94-051); organic matter (XP P 94-047); absolute density (NF EN 1097-6); Modified Proctor (NF P94-093); CBR (NF P 94-078) and the direct shear test will be carried out on mixtures which will comply with the criteria of CEBTP, 1984 [3] . The granite crushed has been subjected to the tests: particle size analysis (NF P 94-056); absolute density (NF EN 1097-6); sand equivalent (EN 933-8); Los Angeles (NF EN 1097-2) and Micro-Deval (NF EN 1097-1).

Study setting

The gravelly laterite (loan abandoned) and the crushed granite 0 / 31.5 studied in this research come respectively from Lokoui (commune of Djakotomey) and Setto (commune of Djidja) in the depot of the company ADEOTI Sarl.

Djakotomey (precisely in the village of Lokoui) is a commune located in south-west Benin in the department of Couffo and with an average altitude of 122m. It is located approximately 99 km from the city of Cotonou. Its geographic coordinates are: Latitude: 6 ° 54 ’0’ ’N; Longitude: 1 ° 43 ’0’ ’E, totaling 325 km^2, or 0.283% of the area of Benin. The climate is Sudano-Guinean or subequatorial with two rainy seasons and two dry seasons alternately and the annual rainfall is 1067 mm.

Djidja is a commune located in the south of Benin in the Zou department and 300 m above sea level. It is located about 36 km northwest of the city of Abomey, in the department of Zou. Its geographic coordinates are: Latitude: 7 ° 20 ’40’ ’N; Longitude: 1 ° 56 ’00’ ’E, totals 131 km^2, or 0.114% of the area of Benin. The climate is subequatorial, tending towards the Sudano-Guinean in the northern parts. Also we notice that in these parts the two rainy seasons become practically one whose average precipitation varies between 900 and 1200 mm.

3 :Djakotomey
Gravelly laterite
Crushed granite

Figure 1:- Geographical map of Benin with the areas of sampling.

Results and Discussions:-

The geotechnical and mechanical characteristics of natural lateritic gravelly

As part of this research, all tests were carried out in the laboratory on each of the three samples in the ADEOTI Sarl depot (granite crushed) and in the loan (lateritic gravelly). Table 1 then Figure 2 give the results of the geotechnical characteristics of the natural lateritic gravelly, then Table 3 and Figure 3 give that of the granite crushed.

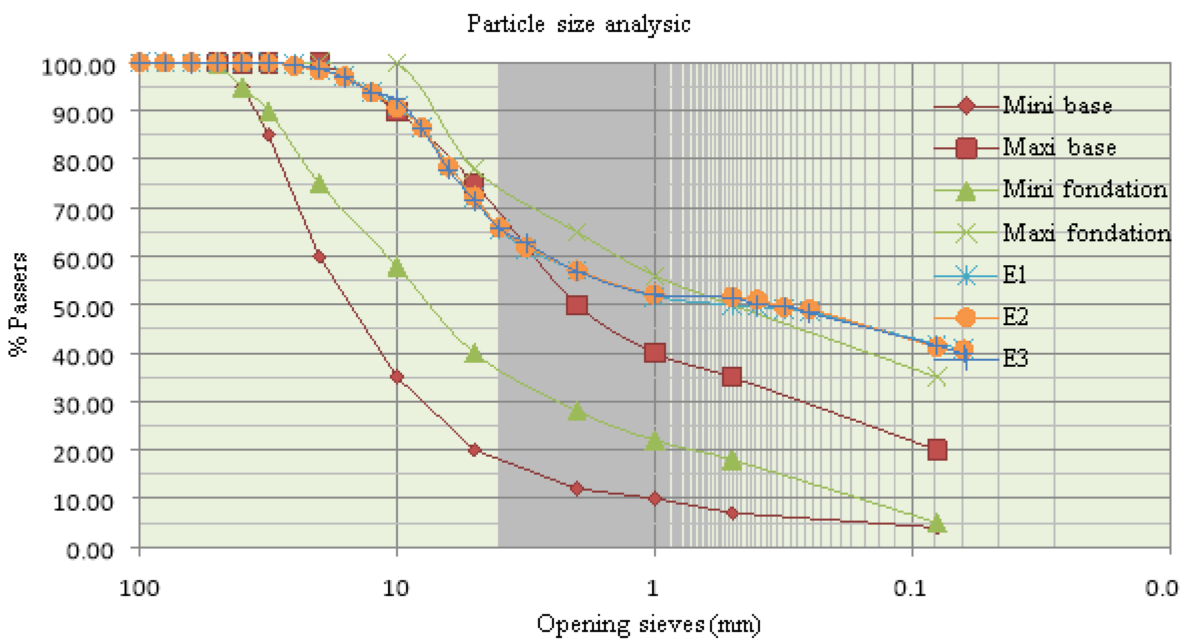

Figure 2:- Particle size curves of the three lateritic gravelly samples.

Table 1:- Geotechnical characteristics of the natural lateritic gravelly.

N^0	Granulometry			Limit of Atterberg			Organic material	Actual density (g/cm^3)	Modified Proctor		CBR index after 96 h of imbibition	
	Dmax (mm)	2mm (%)	0,08mm (%)	WL	WP	IP			W_{opm} (%)	γ_{opm} (t/m^3)	I_{CBR} 100%	I_{CBR} 95 %
1	31.5	57.15	41.81	42	19	23	0.98	2.64	13	1.99	67	35
2	31.5	57.09	41,22	42	18	24	0.95	2.64	13.2	2.0	65	34
3	31.5	56.89	41.52	42	19	23	0.98	2.64	13.1	1,97	66	34
Mean	31.5	57.0	41.5	42	18.7	23.3	0.97	2.64	13.1	1.99	66	34.33
Ecartype	0	0.1	0.3	0	0.6	0.6	0.01	0.0	0.10	0.02	1	0.58

According to the sieve size analysis curves, the upper parts of the curves fit well in the reference spindles but from the 0.6 mm sieve to the last sieve, they extend beyond the spindle. So the percentages of fine elements (class 0/0.6) of lateritic gravelly greatly exceed what is recommended by CEBTP, 1984.

According to the GTR and HRB systems as a function of the plasticity index, liquidity limit and the content of fines C80 µm in the soil, the lateritic gravelly in study is class A2 according to the GTR classification and class A7-6 according to HRB, it is clay soil. The liquid limit of natural lateritic gravelly is 42%, value higher than the recommended maximum which is 35% of the base layer and lower of the base layer according to CEBTP, 1984 whose percentage is 50% maximum. In addition, the plasticity index is 23.3% greater than 15% maximum representing the base layer and less than 30% maximum of the foundation layer. Thus the organic matter found is 0.97%. However, according to Jacques L, 2006, if the organic matter is less than 3%, this material is inorganic. We also note that the dry density with the modified Optimum Proctor is 1.99t / m3, value greater than 1.8 t / m3 recommended by the CEBTP, 1984 for the foundation layer. In addition, the 95% CBR index of OPM is 34.33%

value which is between 25% and 35% recommended by CEBTP, 1984 and the swelling is 0.624% value below 1% maximum recommended. Therefore, we can say that our gravelly is not usable in base layer for the flexible pavements but this gravelly was improved by the granite crushed to be usable in layer of base.

Table 2:- Geotechnical characteristics of granite crushed.

N^0	Granulometry			Sand equivalent	Actual density (g/cm^3)	Los Angeles (%)	Micro-Deval (%)
	Dmax (mm)	2mm (%)	0,08mm (%)	ES (%)			
1	31.5	26.3	4.88	49	2.75	30.71	11.75
2	31.5	27.17	5.82	51	2.78	30.55	11.84
3	31.5	27.02	5.94	50	2.76	30.47	11.87
Mean	31.5	26.8	5.50	50	2.76	30.58	11.82
Ecartype	0	0.5	0.6	1	0.01	0.12	0.06

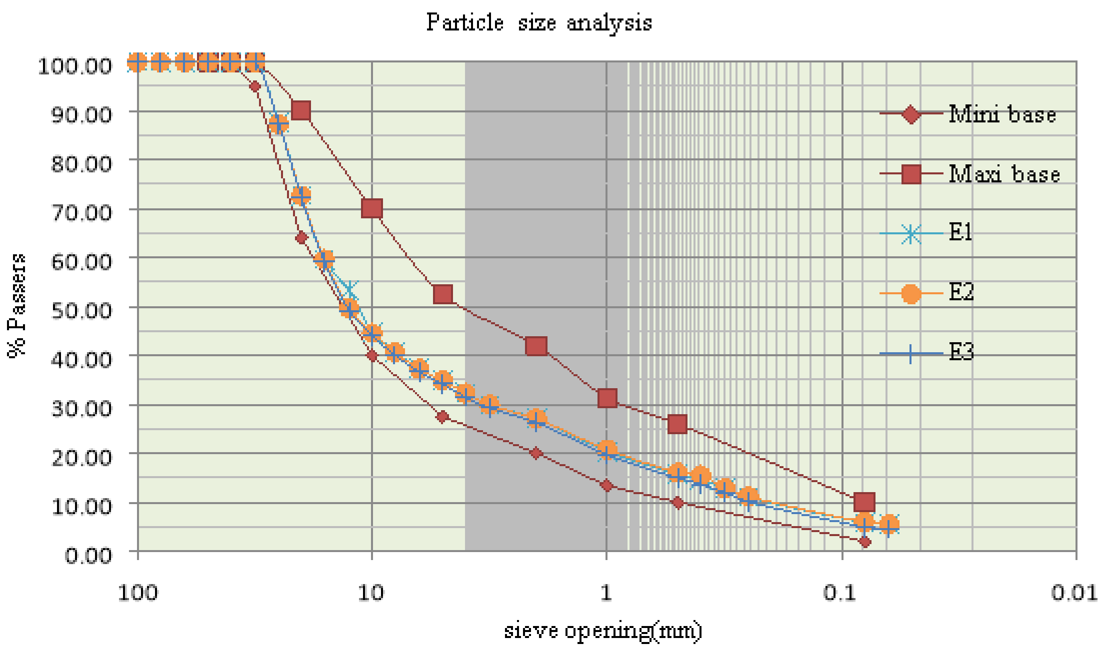

Figure 3:- Particle size curves of the three samples of the granite crushed.

We note that the three granulometric analysis curves of the granitic crushed have the same appearance and fit well in the time zones of the base layer type of the bass of CEBTP, 1984. The percentages of screen refusals 20 mm of the three analysis particle sizes are around 27% higher than the minimum 25% value recommended by the CEBTP, 1984 for the measurement of CBR index. However, the equivalent of gravel sand is 50%, this sand is clean and this value is greater than the minimum 40% recommended for T3 - T4 traffic. On the one hand the value of Los Angeles is 30.58% value below the maximum 45% recommended for traffic T1 - T2, on the other hand the value of Micro-Deval is 11.82% value below the maximum 12% value recommended by the CEBTP, 1984 for T3 - T4 traffic. Furthermore, the optimal porosity is 13.04%, a value less than the maximum 15% recommended by CEBTP, 1984. Therefore, with the excellent characteristics of our granite crushed we can say that this granite crushed is good for improving our laterite.

Results of geotechnical and mechanical tests of mixtures

The physical and mechanical characteristics of the lateritic gravelly are improved with the granite crushed. Therefore, we made the mixes of 20%, 30%, 35% and 40% of the granite crushed with the lateritic gravelly. The results of the various tests carried out on the mixtures are recorded in the following tables and the following figures are the curves of the particle size analyzes by sieving of these mixtures.

Table 3:- Geotechnical characteristics of the mixture of 20% crushed + 80% laterite.

N^0	Granulometry			Limit of Atterberg			Actual density (g/cm^3)	Modified Proctor		CBR index after 96 h of imbibition	
	Dmax (mm)	2mm (%)	0,08mm (%)	WL	WP	IP		Wopm(%)	γ_{opm}(t/m^3)	I_{CBR} 100 %	I_{CBR} 95%
1	31.5	62.13	44.49	45	23	22	2.57	10.2	2.06	83	46
2	31.5	62.27	44.71	45	23	22	2.59	10.3	2.05	82	49
3	31.5	65.79	44.58	45	22	23	2.58	10.1	2.04	81	47
Mean	31.5	63.40	44.59	45	22.7	22.3	2.58	10.2	2.05	82	47.33
Ecartype	0	3.7	2.07	0.11	0.6	0.6	0.008	0.1	0.01	1	1.53

Table 4:- Geotechnical characteristics of the mixture of 30% crushed + 70% laterite.

N^0	Granulometry			Limit of Atterberg			Actual density (g/cm^3)	Modified Proctor		CBR index after 96 h of imbibition	
	Dmax (mm)	2mm (%)	0,08mm (%)	WL	WP	IP		Wopm(%)	γ_{opm} (t/m^3)	I_{CBR} 100%	I_{CBR} 95%
1	40	59.33	43.37	41	21	20	2.67	10	2.075	84.00	48.00
2	40	59.31	43.34	41	21	20	2.67	10,3	2.07	82.00	52.00
3	31,5	59.43	43.28	41	21	20	2.69	9.7	2.072	82.00	49.00
Mean	37,2	59.36	43.33	41.0	21.0	20.0	2.68	10.0	2.072	82.67	49.67
Ecartype	4.9	0.06	0.06	0.0	0.0	0.0	0.007	0.30	0.003	1.15	2.08

Table 5:- Geotechnical characteristics of the mixture of 35% crushed + 65% laterite.

N^0	Granulometry			Limit of Atterberg			Actual density (g/cm^3)	Modified Proctor		CBR index after 96 h of imbibition	
	Dmax (mm)	2mm (%)	0,08mm (%)	WL	WP	IP		Wopm(%)	γ_{opm} (t/m^3)	I_{CBR} 100%	I_{CBR} 95%
1	40	48.78	30.07	35	20	15	2.65	10,3	2.11	85	57
2	40	48.99	30.46	35	20	15	2.68	10.6	2.09	82	55
3	31.5	48.78	30.98	35	20	15	2.68	10	2.1	85	62
Mean	37.2	48.85	30.50	35.0	20.0	15.0	2.67	10.30	2.10	84.0	58.0
Ecartype	4.9	0.12	0.46	0.0	0.0	0.0	0.0016	0.30	0.01	1.73	3.61

Table 6:- Geotechnical characteristics of the mixture of 40% crushed + 60% laterite.

N^0	Granulometry			Limit of Atterberg			Actual density (g/cm^3)	Modified Proctor		CBR index after 96 h of imbibition	
	Dmax (mm)	2mm (%)	0,08mm (%)	WL	WP	IP		Wopm(%)	γ_{opm} (t/m^3)	I_{CBR} 100%	I_{CBR} 95 %
1	40	41.40	24.62	37	22	15	2.64	7.8	2.135	90	60
2	40	42.64	25.66	37	23	14	2.64	8.2	2.119	93	58
3	31.5	41.50	26.01	37	23	14	2.64	8	2.124	89	59
Mean	37.2	41.85	25.43	37.0	21.0	14.3	2.64	8.000	2.126	90.67	59
Ecartype	4.9	0.69	0.72	0.0	0.0	0.6	0.0	0.200	0.008	2.08	1

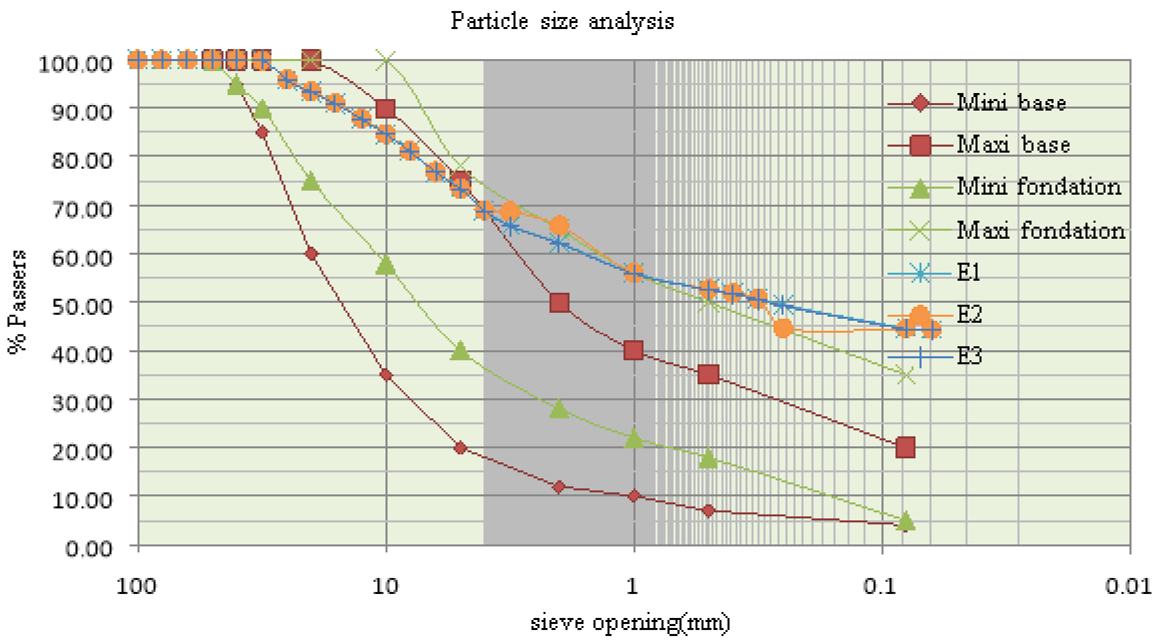

Figure 4:- Particle size curves of the three samples of the 20% crushed + 80% mixture of lateritic gravelly.

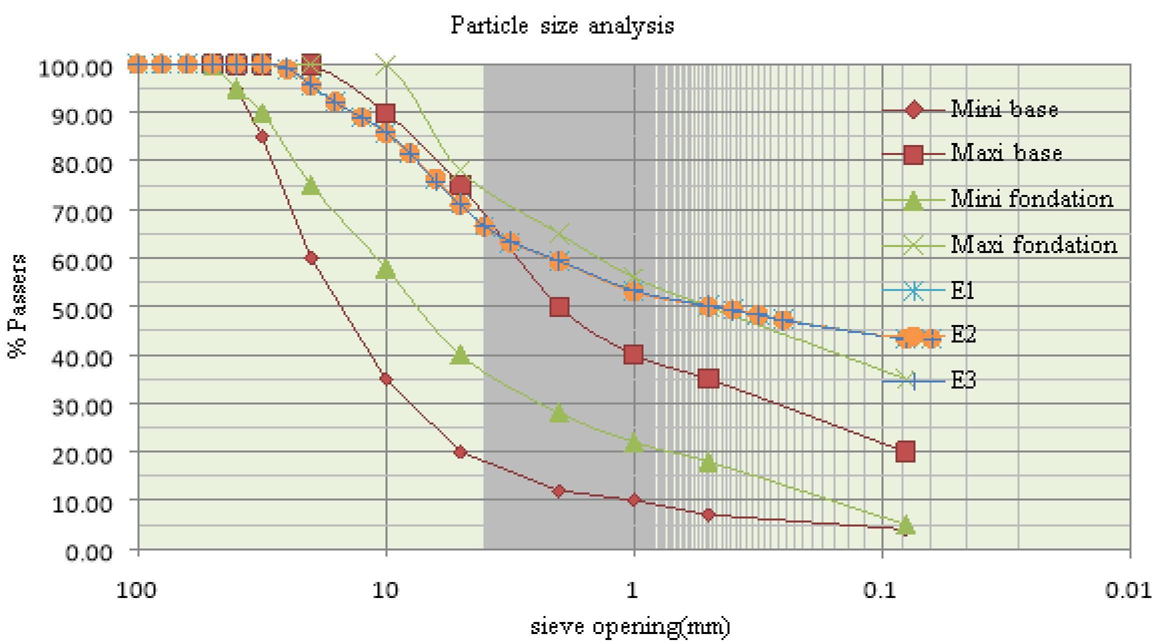

Figure 5:- Particle size curves of the three samples of the 30% crushed + 70% mixture of lateritic gravelly.

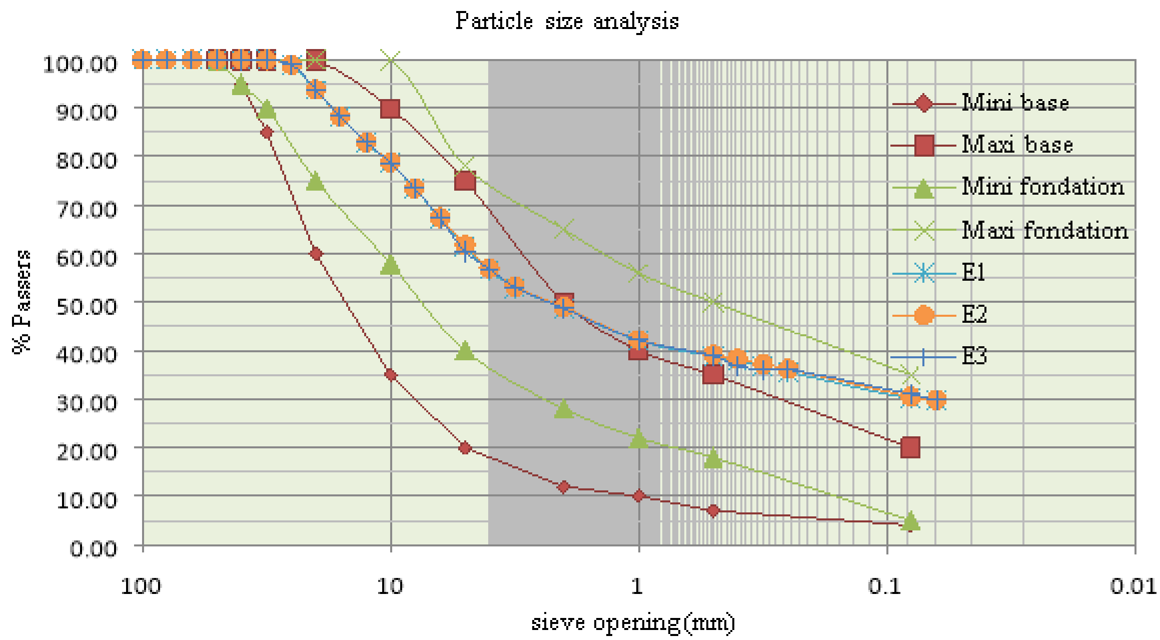

Figure 6:- Particle size curves of the three samples of the 35% crushed + 65% mixture of lateritic gravelly.

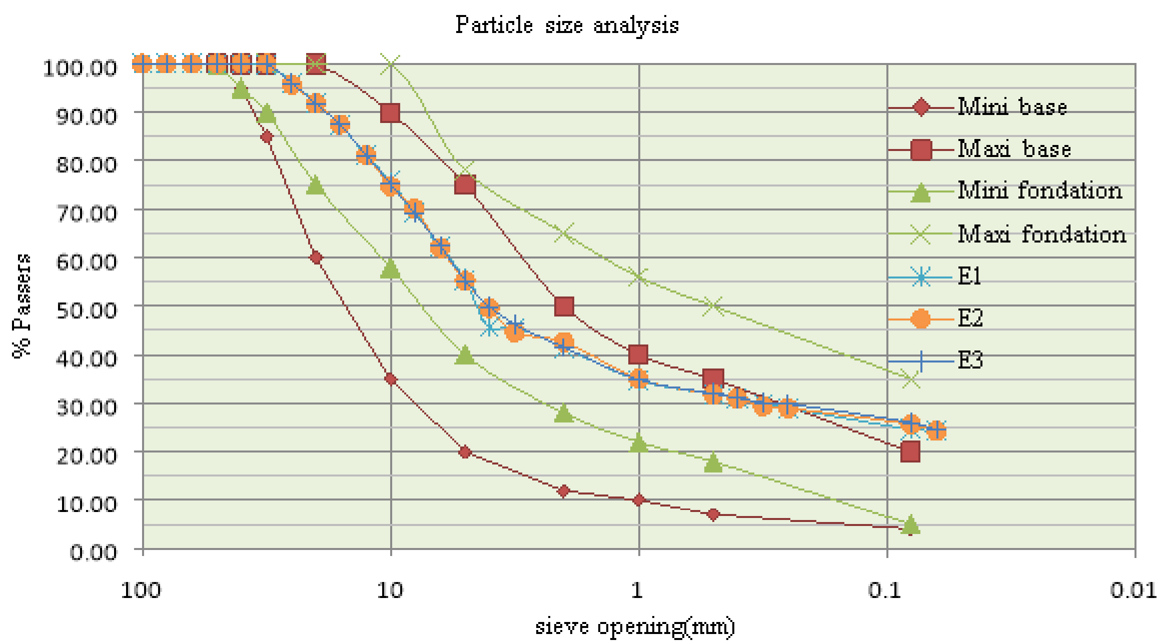

Figure 7:- Particle size curves of the three samples of the 40% crushed + 60% mixture of lateritic gravelly.

In addition, we have been able to note that the particle size analysis curves of the mixtures: 20% granite crushed + 80% of the lateritic gravelly and 30% granitic crushed + 70% of the lateritic gravelly extend beyond the spindles. These mixes cannot be used as a base layer for flexible pavements; on the other hand, those of the mixtures 35% granitic crushed + 65% of the lateritic gravelly and 40% granitic crushed + 60% of the lateritic gravelly fit in well with the time zones of the base layer type of the gravelly soils of CEBTP, 1984. Note that the plasticity index gradually decreases from 23.3% of the natural lateritic gravelly to 14.3% of the 40% granite crushed mixture + 60% of the lateritic gravelly, same observation made by: Toe JM, 2007; NDIAYE M., 2013; Niangoran K., 2020. [15; 12;

13]. On the one hand the liquidity limits of the mixes 35% and 40% of the granite crushed are respectively 35% and 37%, values higher than the maximum recommended 35% at the base layer and lower than 50% maximum of the foundation layer of CEBTP, 1984. On the other hand their plasticity indices are respectively 15% and 14.3% less than or equal to 15% maximum at the base layer and less than 20% of the foundation layer. Their dry densities with the modified Optimum Proctor are 2.1t / m^3 and 2.126t / m^3 respectively values greater than 1.8 t / m^3 recommended by the CEBTP, 1984 for the foundation layer. Also the CBR indices at 95% of the OPM of these two mixtures are 58% and 49% respectively of the values which exceed the 35% maximum recommended by the CEBTP, 1984 as well as their swellings are less than 1% maximum recommended. Of all the above, the two mixtures (35% and 40% of the granite crushed) can be used as a foundation layer for flexible pavements.

On the other hand, the direct shear test was carried out on the laterite and these two mixtures in order to validate the criteria for improving the laterite for the realization of the foundation layer of flexible pavements. The results of this test are shown in Table 8.

Table 8:- Mechanical characteristics of the mixtures (35% crushed + 65% laterite; 35% crushed + 65% laterite) and natural laterite.

Optimum Proctor Modified (OPM)	**N^0**	**Natural laterite**		**35% crushed + 65% laterite**		**40% crushed + 60% laterite**	
		Cu (kPa)	φu (^{0})	Cu (kPa)	φu (^{0})	Cu (kPa)	φu (^{0})
100% OPM	1	23.64	26.83	24.28	30.04	5.24	27.48
	2	24.20	25.42	26.86	30.76	5.56	27.07
	3	24.95	26.44	28.25	30.1	3.44	27.7
	Mean	24.26	26.23	26.46	30.30	4.75	27.42
	Ecartype	0.66	0.73	2.01	0.40	1.14	0.32
95% OPM	1	2.92	24.83	2.75	29.57	4.55	26.49
	2	2.68	24.97	5.04	29.05	6.14	25.96
	3	3.79	24.55	3.90	29.28	8.64	25.39
	Mean	3.13	24.78	3.90	29.30	6.44	25.95
	Ecartype	0.58	0.21	1.15	0.26	2.06	0.55

We note that all the mechanical properties (Cu cohesion and internal friction angle φu) of the two mixtures (35% crushed + 65% laterite and 40% crushed + 60% laterite) are superior to those of natural laterite except the cohesion of the mixture 40% crushed + 60% laterite to 100% of modified Optimum Proctor. We can say that this laterite treatment technique improves the cohesion of natural laterite and reduces the empty spaces between the grains and makes it dense. These results confirm that the laterite treated with crushed stone makes it rigid and dense.

Conclusion:-

This research presents a study of the geotechnical and mechanical characteristics of improved laterite to granite crushed. Before this improvement, the natural gravelly was characterized, it is class A2 according to the GTR classification and class A7-6 according to HRB, it is clay soil. Referring to the criteria of CEBTP, 1980, the gravelly laterite cannot be used as a base layer for flexible pavements. This led to its improvement with granite crushed with better geotechnical characteristics.

Thus, the 35% and 40% mixtures of granite crushed are mixtures whose geotechnical properties meet the criteria of CEBTP, 1984 and can be used as a base layer for flexible pavements. Indeed, the direct shear test made it possible to determine the cohesion and the internal friction angle of the two mixtures meeting the criteria of CEBTP, 1984.

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